PHYSICAL CHANGES IN THE GUNNISON AND COLORADO RIVERS RESULTING FROM CONSTRUCTION OF THE ASPINALL UNIT AND RELATED PROJECTS, WITH HYPOTHESES TO ASSESS THE EFFECTS ON THE ENDANGERED FISHES

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INTRODUCTION

The large rivers of the Upper Colorado River Basin provide habitat for four native fish species that are considered endangered by the U. S. Fish and Wildlife Service: Colorado squawfish *Ptychocheilus lucius*, razorback sucker *Xyrauchen texanus* (to be listed as endangered in May, 1991), humpback chub *Gila cypha*, and bonytail *G. elegans*. Beginning in the late 1800's and continuing today, technologic man's activities have dramatically altered the Colorado River ecosystem. These man-induced changes are generally considered to be responsible for the decline of the four endangered fishes (Miller 1961, Minckley and Deacon 1968, Holden and Stalnaker 1975). The most dramatic physical change has been the alteration of natural flow regimes by water development projects on the tributaries and mainstem rivers of the basin (e.g. Vanicek et al. 1970). Other changes that may have affected the native species include the introduction of fishes that may compete with or prey upon the native fishes, and poor watershed management practices that affect the quality and quantity of water in the basin.

Although many private irrigation projects already existed, development of water storage in the Upper Colorado River Basin began in earnest during the 1930's with the construction of several projects by the Bureau of Reclamation. Reservoir construction in the upper basin increased dramatically in the 1950's and 1960's with the Colorado River Storage Project (CRSP). This project built dams on large rivers in the Upper Colorado River Basin. Three of these dams (Glen Canyon, Flaming Gorge, and Navajo) were built within habitat historically inhabited by the four listed species. Three additional dams (the Aspinall Unit--Blue Mesa, Morrow Point, and Crystal) were built on the upper Gunnison River, upstream from reaches historically inhabited by the endangered fishes. A number of participating projects were also built in conjunction with CRSP. The combined operation of these projects has dramatically altered the Colorado River ecosystem, and thus negatively affected the endangered fishes. The Aspinall Unit was completed before passage of the Endangered Species Act; therefore, its effect on native fishes was not considered before construction began. However, the operation of the Aspinall Unit and other CRSP reservoirs continues to effect the endangered fishes, and Section 7 consultation under the Act is required on the Bureau's annual operation of the dams. In addition, two projects--Dolores (McPhee Reservoir on the Dolores River) and Dallas Creek (Ridgeway Reservoir on the Uncompahgre River) were recently constructed on tributaries to the Gunnison and Colorado rivers (Figure 1). These reservoirs did undergo Section 7 consultation, and were built with the stipulation that water from the Aspinall Unit would be used to partially offset the effects of these two projects on the endangered fishes. Studies to evaluate the effects of the operation of Flaming Gorge and Glen Canyon dams on endangered fishes in the Green and lower Colorado rivers are ongoing. The purpose of this document is to: 1) describe changes in the Gunnison and upper Colorado rivers as a result of the Aspinall Unit and the two recent projects, and 2) to hypothesize how these changes have affected the native fish community. This information will be used to design studies to test these hypotheses and to assess the benefits for endangered fishes that could be achieved by modifying the release pattern of the Aspinall Unit.

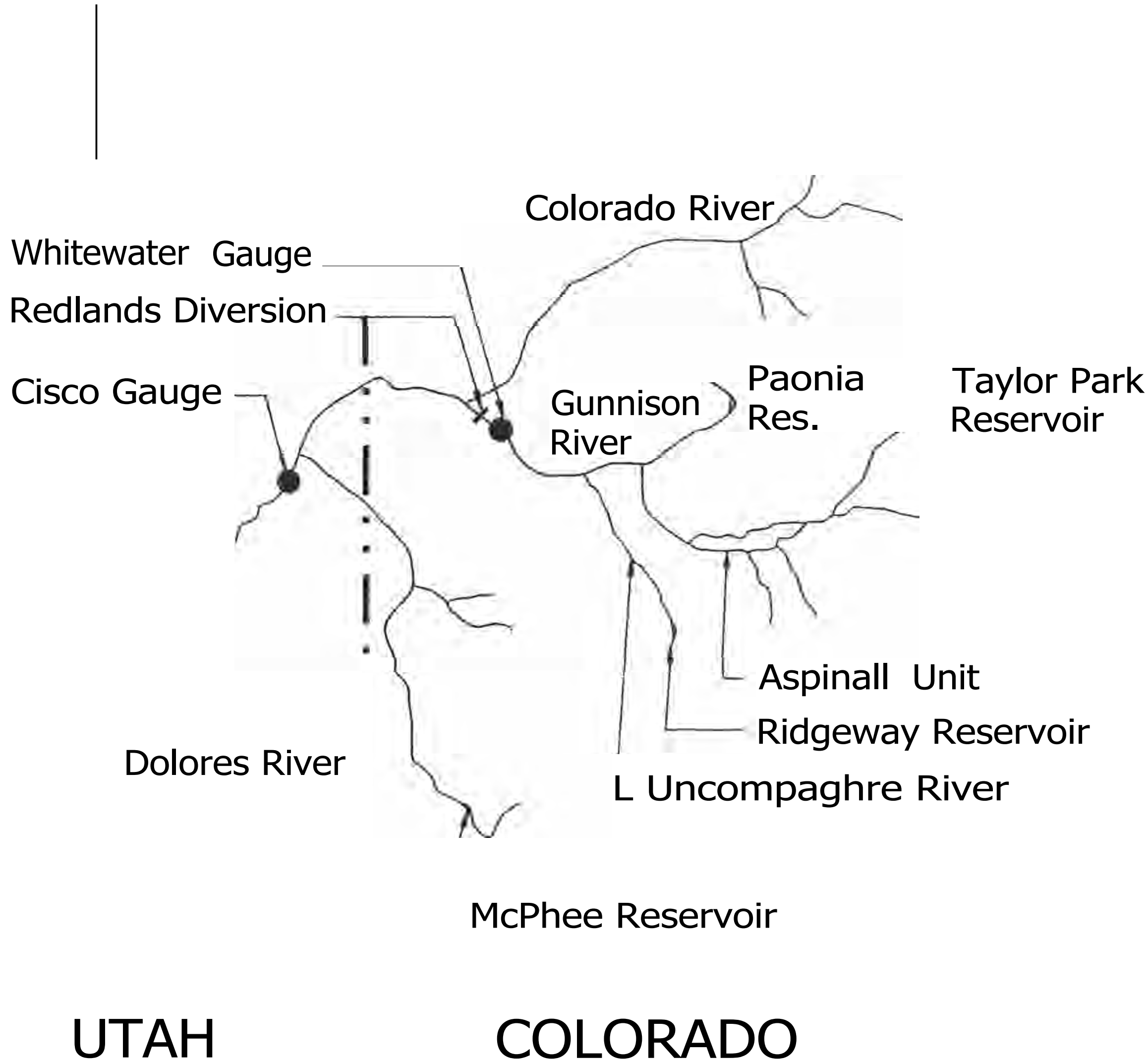

Figure 1. Important features in the Upper Colorado and Gunnison River subbas ins.

BACKGROUND

Water Development

Private irrigation development in the Gunnison River basin began in the 1880's, with an estimated 180,000 acres under irrigation by 1906 (USBR 1990). Consumptive water use was estimated to be 229,000 AF per year by that time. The Redlands Diversion, a barrier to upstream passage of fish, was built on the lower Gunnison River in 1918. The Redlands Diversion has a high-priority water right to divert 750 cfs and can dry up the Gunnison River below the dam during extremely low-flow periods. However, about 700 cfs of this water reenters the Colorado River a few miles downstream from the mouth of the Gunnison River. Federal involvement in the basin began in 1909 with the completion of the Gunnison Tunnel which diverts water from the Gunnison River into the Uncompahgre River Valley. Taylor Park Dam, on the Taylor River in the headwaters of the Gunnison, was completed in 1937 to provide water storage for the Gunnison Tunnel (see Table A8 for a summary of the storage capacity of reservoirs mentioned in the text). Diversion structures were placed on the Gunnison and Uncompahgre rivers as part of this project. Annual diversions for this project average about 559,000 acre feet--about half of this flow is used consumptively and the remainder ultimately enters the Gunnison River near Delta. An estimated 246,000 acres were irrigated in the basin by 1960, with about 466,000 AF of consumptive water use (USBR 1990).

The Aspinall Unit Reservoirs--Blue Mesa, Morrow Point, and Crystal--were completed in 1966, 1970, and 1976 respectively. Gunnison River flows are controlled by Blue Mesa Reservoir, the largest of the three reservoirs (see Table A8 for reservoir capacity). Crystal, the lower most reservoir, re-

regulates releases from Blue Mesa and Morrow Point, which are operated as peaking power facilities. The Aspinall Unit was constructed to provide water storage and hydroelectric power generation as well as to provide flood control, recreation, and fish and wildlife benefits. A primary purpose was to store water for delivery to the lower basin under the requirements of the Colorado River Compact. Consequently, the reservoirs of the unit store water during spring runoff, and release it gradually throughout the rest of the year. The Unit also produces electrical energy in conjunction with the other dams of the CRSP. The energy and water needs of the system dictate the schedule and volume of water releases into the Gunnison River. The net result of this method of operation is to decrease peak discharge during the runoff period and to increase streamflow during the rest of the year. A secondary effect is that water temperature is decreased during summer and increased during winter. These modifications are typical of the ecological changes in a river after the construction of a large dam (e.g. Vanicek et al. 1970).

Other water-development projects constructed by the Bureau of Reclamation in the Gunnison River Basin include: Crawford Dam (Smith Fork Project), on a tributary to the Gunnison River, completed in 1962; Paonia Dam, on the North Fork of the Gunnison River, completed in 1962; Fruitgrowers Reservoir, a small reservoir on a tributary to the Gunnison River, completed in 1939; Ridgeway Reservoir (Dallas Creek Project), on the Uncompahgre River, completed in 1987.

Bureau of Reclamation projects in the Colorado River Basin upstream from the Gunnison River include: Grand Valley Project, completed in 1915; Colorado-Big Thompson Project, which includes Green Mountain, Willow Creek, Grandby, and Shadow Mountain dams, completed 1943-1956; Fryingpan-Arkansas Project, Reudi Dam, completed 1969. Colbran Project, Vega Reservoir, completed 1960. Silt Project, Rifle Gap Dam, completed 1967. McPhee Reservoir was built on the Dolores River (tributary to the Colorado River downstream from the Gunnison) in 1984.

Biological

Colorado squawfish

Historical information on the distribution of the endangered fishes in the upper Colorado and Gunnison rivers is limited. Jordan (1891) reported Colorado squawfish as common in the upper Colorado River. He also captured some specimens from the Gunnison and Uncompaghre (tributary to the Gunnison) rivers near Delta. Ellis (1914) collected fish from the Colorado and Gunnison rivers near Grand Junction, but did not report any Colorado squawfish. The next documented fish collections did not occur in the area until the 1940's when Chamberlain (1946) reported Colorado squawfish from the lower Gunnison River. Kidd (1977) reported that a commercial fisherman collected Colorado squawfish from the Gunnison River near Delta from 1930 until 1950 (50 in 'one of the better years'). Wiltizus (1978) believed that the Redlands Diversion Dam reduced Colorado squawfish numbers in the Gunnison River by preventing upstream movement from the Colorado River. However, Valdez et al. (1982a) collected eight adult-size Colorado squawfish from the Gunnison River above Redlands Dam. Osmundson and Kaeding (1989) collected one larval Colorado squawfish just downstream from the Redlands Dam in 1986; it is not known whether the larvae was spawned above or below the dam. Wick (personal communication) believes that high-quality, adult Colorado squawfish habitat still exists in the Gunnison River.

Quantitative collections began in the upper Colorado River in the late 1960's when Holden and Stalnaker (1975) reported finding small numbers of Colorado squawfish throughout their study area. More intensive, but localized collections in the Grand Junction area in the mid 1970's (Kidd 1977, Seethaler 1978) resulted in considerably more Colorado squawfish than had been previously reported. The larger numbers were probably a reflection of increased effort rather than increased numbers of Colorado squawfish. Recent collections (Valdez et al. 1982b, Archer et al. 1985, Osmundson and Kaeding 1989) indicate that Colorado squawfish are still present in the Colorado river in numbers about that of the 1970's. Although documentation is difficult, it is likely that Colorado squawfish populations had already declined by the time quantitative collections began. Colorado squawfish are less common than they were in the early 1900's, but documentation of the degree of change is impossible.

Razorback sucker

Razorback suckers were also apparently abundant in the Colorado and lower Gunnison rivers. Jordan (1891) considered the razorback sucker to be abundant in the upper Colorado River and collected some specimens from the Gunnison and Uncompahgre rivers near Delta. Chamberlain (1946) reported the razorback sucker as common in the Gunnison River downstream from Delta. Osmundson and Kaeding (1989) cited reports by long-time residents along the Colorado river of 'several thousand' razorback suckers using flooded areas adjacent to the river during the 1930's and 1940's. Kidd (1977) reported their frequent collection by a commercial fisherman near Delta between 1930 and 1950. Kidd (1977) and McAda and Wydoski (1980) collected a combined total of 284 razorback suckers in the Grand Junction area from 1974 to 1976. However, very few were collected during the late 1980's (summarized by Osmundson and Kaeding 1990). Although some of this decline may be related to habitat change at the Walker Wildlife Area where Kidd (1977) and McAda and Wydoski (1980) collected most of their fish and to decreased sampling intensity, the abrupt population decrease appears real. Intensive sampling by the Fish and Wildlife Service and Colorado Division of Wildlife in 1989 and 1990 collected only 3 razorback suckers in the Colorado River (Kaeding and Osmundson 1990; Bob Burdick, personal communication). Wiltzius (1978) collected one razorback sucker from the Gunnison River in 1975, but Valdez et al. (1982a) did not collect any during 1979 to 1981. Although razorback suckers are not presently found in the Gunnison River above Redlands Diversion Dam, suitable habitat still remains (E. Wick, personal communication).

Humpback chub

No historical distribution and abundance data exist for humpback chub because the species was not described until 1946 (Miller 1946). Humpback chub were first collected in the upper Colorado River in 1974 at Black Rocks, upstream from the Utah-Colorado border (B. Burdick, personal communication). Additional populations were later discovered in Westwater and Cataract canyons (Valdez et al. 1982b). Recent studies (Kaeding et al. 1990) suggest that the populations are small and disjunct, but relatively stable. Although Valdez et al. (1982a) extensively sampled the lower Gunnison River from 1979 to 1981, they did not collect any humpback chub.

Bonytail

Historical information about the distribution and abundance of bonytail is limited. Jordan (1891) collected one specimen in the Gunnison River and Ellis (1914) collected some bonytail in the Colorado River near Grand Junction. However, collections during the early 1900's may have confused roundtail chub and bonytail, as they were considered the same species until 1970 (Holden and Stalnaker 1970). Holden and Stalnaker (1975) did not collect any bonytail from the upper Colorado River, but Kaeding et al. (1986) reported one specimen from Black Rocks and Valdez (1990) collected 19 specimens tentatively identified as bonytail in Cataract Canyon. The species is extremely rare in the upper Colorado River basin.

METHODS

We attempted to document the changes to the Gunnison and Colorado rivers that can be attributed to the Aspinall Unit and the two later projects (Dallas Creek and Dolores). Although changes in streamflow can be readily documented at two long-term USGS gages in the Basin, the precise percentage of change attributable to these projects is difficult to determine. A number of projects in both the Gunnison and Colorado River basins were constructed at the same time as the Aspinall Unit. All of these projects affected the rivers--determining the effect of one project among many is problematic. We were primarily concerned about three major impacts to the Colorado and Gunnison rivers: streamflow (timing and quantity), water temperature, and sediment load.

Water Temperature

Water temperature data are not available for the Gunnison River prior to construction of the Aspinall Unit. The only available data were taken with a thermograph near the Uncompahgre Project tunnel in 1964 and 1965 (Kinnear 1967). Wiltzius (1978) used these data to predict that the maximum water temperature change in the tunnel area would be a decrease of 6 to 12 °F during the spring and summer months. Stanford and Ward (1983) documented water temperatures at Crystal Dam (just upstream from the tunnel) in 1979-1980 that were as much as 10 °C lower than those recorded by Kinnear (1967).

We used the above information to assume a 'worst case' temperature change below Crystal Dam of -6 °C during March, April, May, and September, and -11 °C during June, July, and August. We added these amounts to recent water temperature data below Crystal Dam to approximate water temperatures that might have occurred prior to construction of the Aspinall Unit. We then estimated changes in mean, bi-monthly water temperature for March through September at two locations in the Gunnison River (river miles 2 and 20) and two locations in the Colorado River (river miles 49 and 136) using the Stream Network Temperature Model (SNTEMP; Theurer et al. 1984). SNTEMP is a mechanistic, one-dimensional heat transport model that predicts the daily mean and maximum water temperature as a function of stream distance and environmental heat input. SNTEMP is applicable to a stream network of any size or order. It includes (1) a solar model to predict the solar radiation that penetrates the water by latitude and time of year, (2) a shade model that predicts the riparian and topographic shading, (3) algorithms that make meteorological corrections used to predict changes in air temperature, relative humidity, and atmospheric pressure by elevations within the watershed, and (4) regression algorithms that smooth and fill in missing water temperature measurements. Turbulence is assumed to thoroughly mix the stream vertically and transversely.

Sediment Load

Relatively little information is available about sediment changes in the Gunnison and Colorado rivers. Information from two reports (Thompson 1984; Elliott and DeFeyter 1986) was summarized to evaluate changes in sediment load carried by the two rivers as a result of the Aspinall Unit.

Streamflow

Our primary method of assessing the effects of the Aspinall Unit and related projects on streamflow was to compare measurements at two long-term USGS stream gaging stations--Gunnison River at Whitewater (begun in 1917) and Colorado River at Cisco (begun in 1914). Unfortunately, irrigation diversions began as early as 1880 in the two basins and we have no reliable method of accounting for these diversions in the available streamflow data. In addition, two large water diversions (Uncompahgre tunnel in 1909 and the Redlands Diversion Dam in 1918) were constructed at about the same time that flow measurements began. These projects diverted water from the rivers but did not provide any storage. Also, because the water was used for irrigation, some of the diverted water returned to the rivers upstream from the selected gaging stations. Therefore, we believe that the measured streamflow probably underestimates the historic streamflow that occurred during non-runoff periods, but probably approximates the streamflow that would have occurred during runoff periods when only a small portion of the flow could be diverted. Dam construction began in the Gunnison Basin with the closure of Taylor Park

Dam in 1936. Dam construction began in the upper Colorado River shortly after that (i.e. Green Mountain Dam in 1942). The first dam of the Aspinall Unit (Blue Mesa) closed in 1965. Therefore, to accommodate the changes in water usage during the period of record, we divided the available streamflow data into three periods: early development (1914-1936), middle development (1937-1965), and post-Aspinall development (1966-1989). We compared post-Aspinall streamflow with early- and middle-development streamflows to determine the effect of the Aspinall Unit on streamflow in the Gunnison and Colorado rivers.

We also used synthesized data (HDR Engineering, Inc. 1989) to estimate what Gunnison River flows would have been during the middle-development and post-Aspinall periods without any water development in the basin. The synthesized data were only available for 1952 through 1983, so we compared it with actual streamflow for those years to estimate the effect of Aspinall on Gunnison River flows. These estimates served to validate changes estimated with the previously described method and to provide an estimate of the effect of early irrigation diversions on streamflow.

EFFECT OF THE ASPINALL UNIT ON THE GUNNISON AND COLORADO RIVERS

Water Temperature

The synthesized water temperature data showed a large difference between pre- and post-Aspinall temperatures at Crystal Dam. However, the water warmed rapidly as it moved downstream--water temperatures differed by a maximum of 2 °C at river mile 20 (Figure 2, Table A1). River mile 20 is midway through the reach of Gunnison River currently inhabited by Colorado squawfish (Valdez et al. 1982a). The observed difference was less at the mouth of the Gunnison River (Figure 2). Water temperature in the Colorado River is essentially

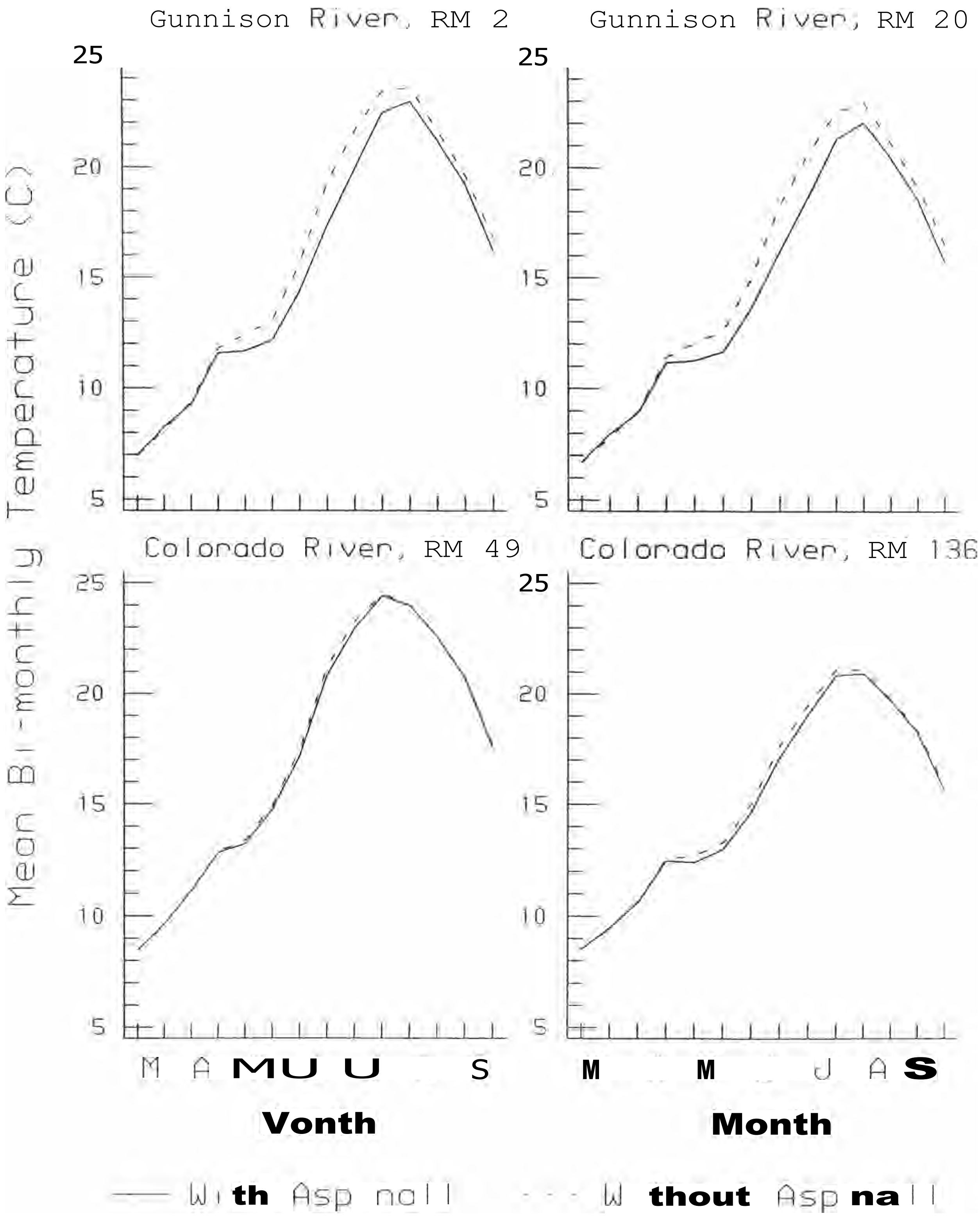

Figure 2. Estimated effect of the Aspinall Unit on mean, bi—monthly water temperature at two locations in the Gunnison River and two locations in the Colorado River.

unaltered by the Aspinall Unit. Current water temperatures at both sites in the Colorado River (RM 136 and 49) differed from the estimated pre-Aspinall temperatures by a maximum of 0.5 °C (Figure 2, Table A2).

Sediment Load

The average annual suspended-sediment load of the Gunnison River is highly variable (Elliott and DeFeyter 1986), but has declined as a result of the Aspinall Unit (Figure 3, Table A3). The Aspinall Unit has not reduced the minimum amount of sediment carried by the river, but has reduced year to year variability. Thompson (1984) summarized the suspended-sediment load of the Colorado River near Cisco for 1930-1982 (Figure 4). He attributed a break in the slope of the relation between annual suspended-sediment load and annual stream discharge to the construction of the Aspinall Unit. The slope change indicated that the average annual suspended-sediment load decreased after the construction of Aspinall. Although other factors (e.g. changing land use patterns) may have contributed to reduced sediment loads, the abrupt change in slope at the same time that Blue Mesa was closed suggests that the Aspinall Unit was the primary cause. The reduced sediment load has resulted in larger substrate sizes and an armored bottom in much of the Gunnison River (Stanford and Ward 1983). The changes in the Colorado River are less evident, but may ultimately result in a gradual lowering of the river channel as fine materials are moved downstream and not replaced at an equal rate.

Streamflow

The greatest change caused by the Aspinall Unit is the reduction of spring runoff. Peak discharge has steadily declined since continuous flow records began in the early 1900's (Figures 5, 6, A3, and A4; Table A4). Mean

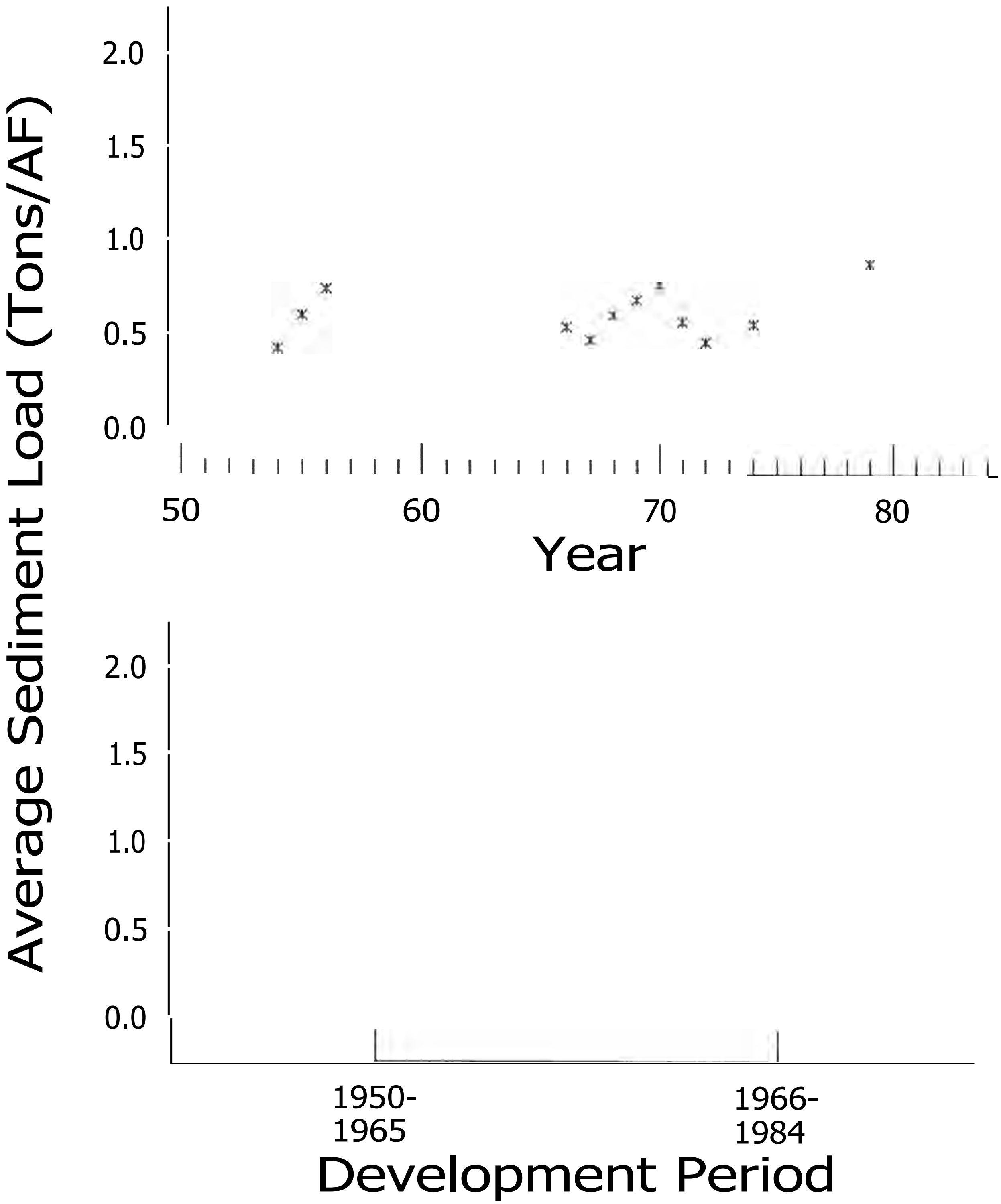

Figure 3. Average annual suspended-sediment load (tons/AF; upper) and mean of the average suspended-sediment load for the pre- and post-Aspinall periods (lower) in the Gunnison River near Grand Junction.

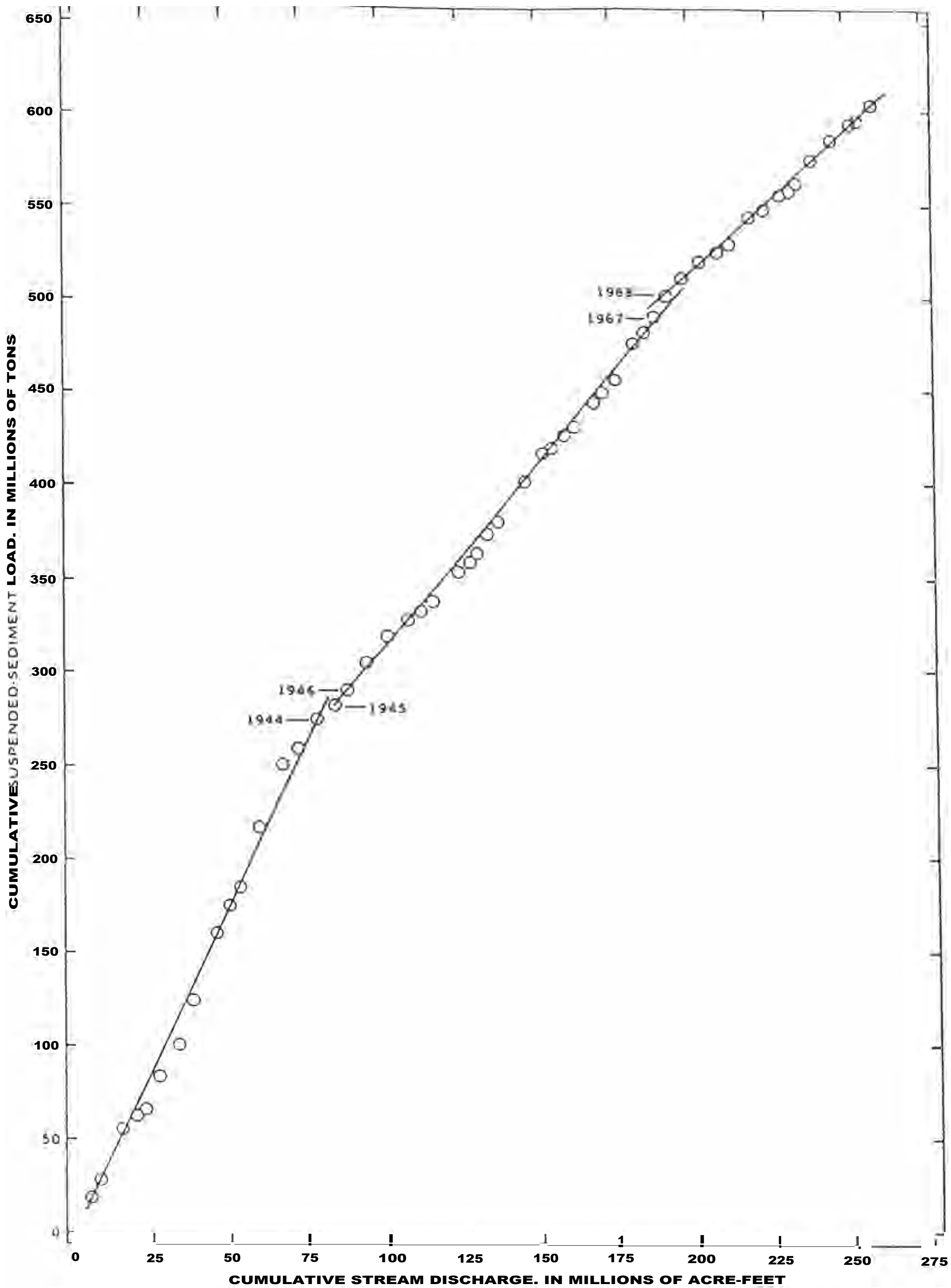

Figure 4. Double mass curve showing relation between annual suspended-sediment load and annual stream discharge in the Colorado River at the Cisco gage, water years 1930-1982. (excerpted from Thompson 1984)

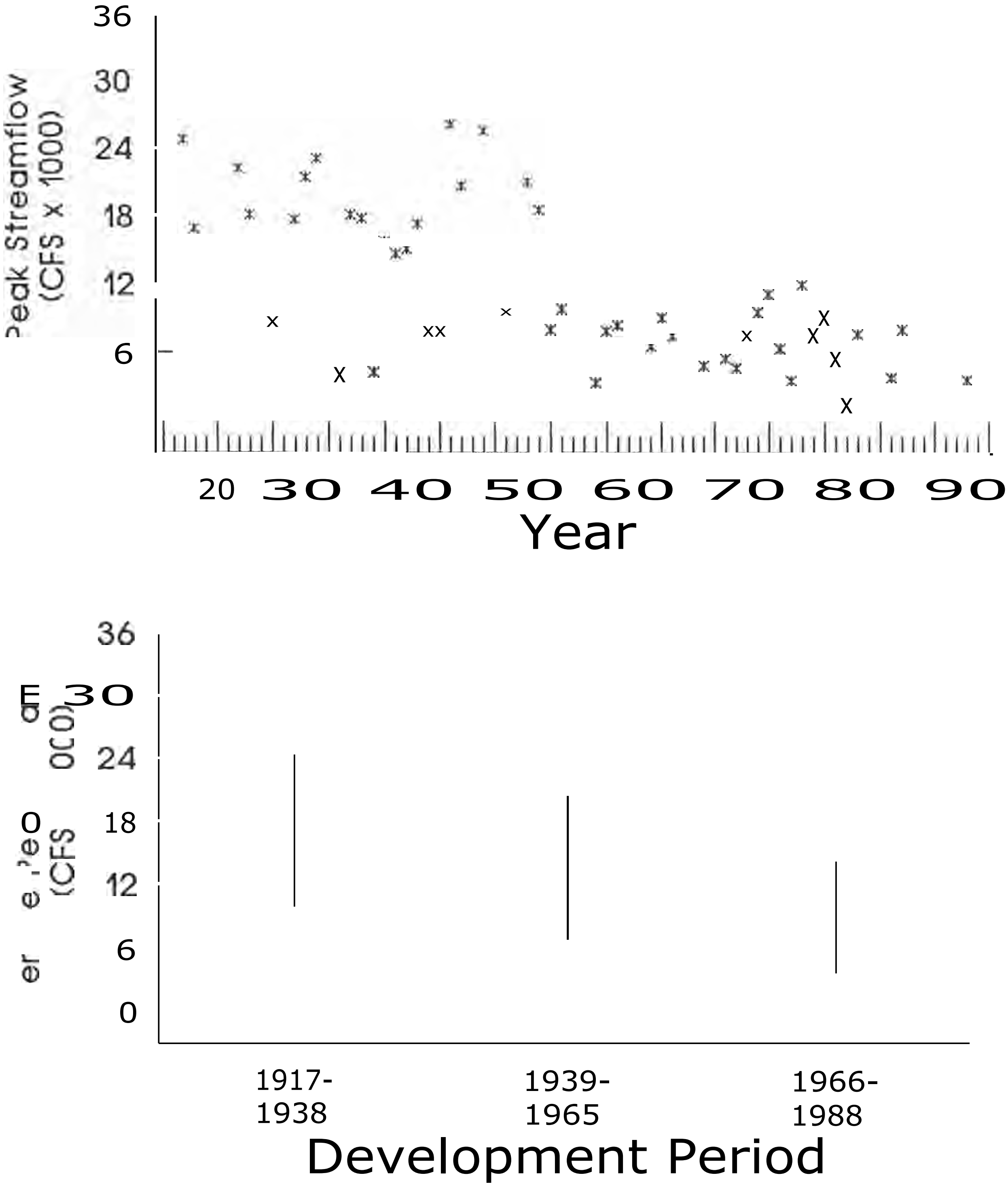

Figure 5. Peak streamflow (highest mean-daily streamflow for the year; upper) and average peak streamflow for three periods (early development [1917-1938], middle development [1939-1965], and post-Aspinall development [1966-1988]; lower [mean ± 1 SE, minimum and maximum]) for the Gunnison River near Grand Junction, Colorado. Streamflows were recorded at the U.S.G.S. stream gage at Whitewater.

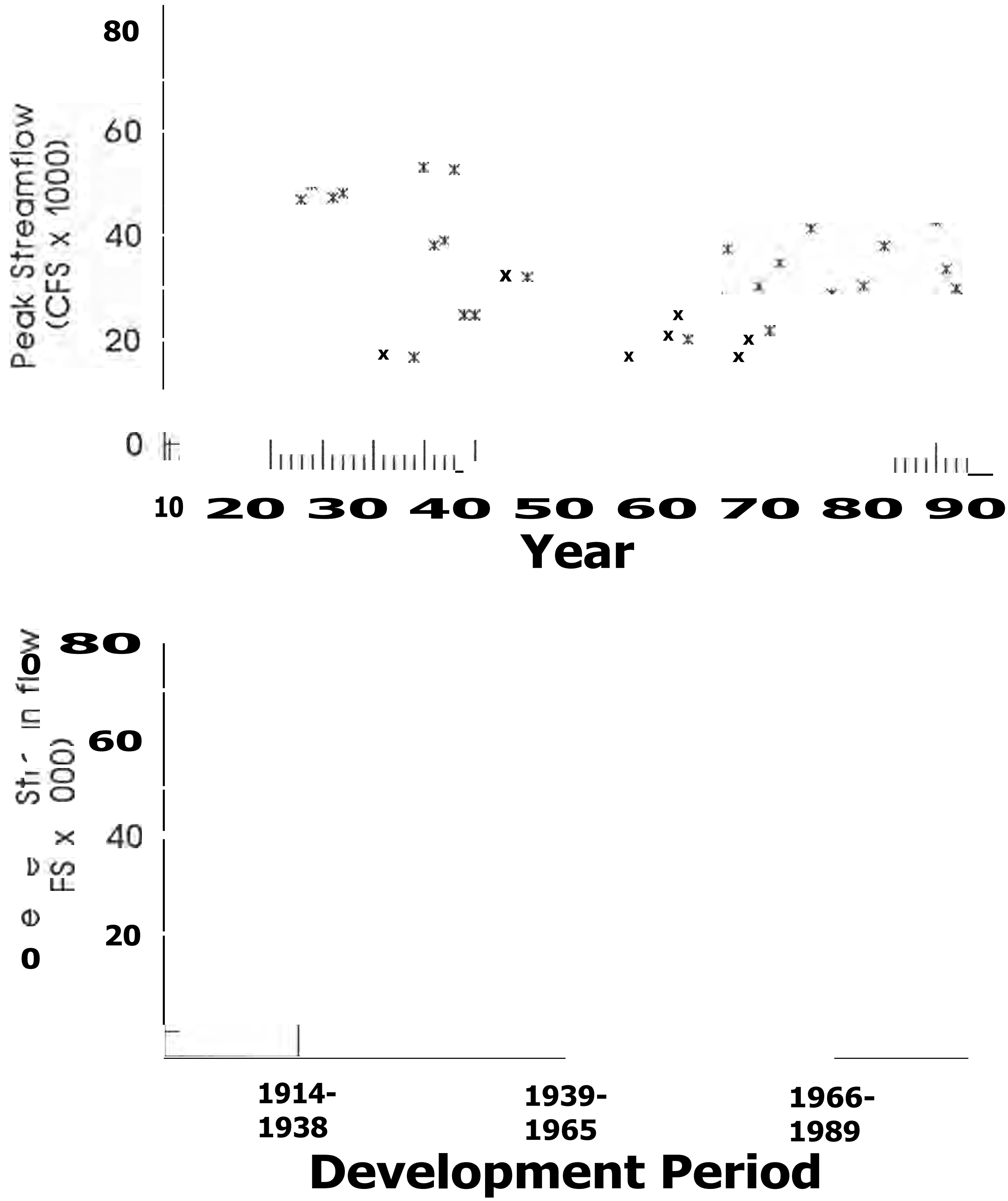

Figure 6. Peak streamflow (highest mean-daily streamflow for the year; upper) and average peak streamflow for three periods (early development [1914-1938], middle development [1939-1965], and post-Aspinall development [1966-1988]; lower [mean ± 1 SE, minimum and maximum]) for the Colorado River at Cisco, Utah. U.S.G.S. stream gage 09180500.

maximum-annual discharge (average of the mean-daily flow for the highest day of the year) for the Gunnison River declined about 47% between the early development and post-Aspinall periods (Table 1). It declined about 37% in the Colorado River (Cisco gage) between the same two periods (Table 1). Mean-monthly flows have also changed over the three development periods (Figure 7; Tables A5 and A6). In general, spring and early summer flows have declined, and fall **and** winter flows have increased. Mean-monthly flows in May and June, the primary runoff months, have declined 43 and 47% (respectively) in the Gunnison River (Table A5), and 31 and 37% in the Colorado River (Table A6).

Flow changes calculated by comparing actual Gunnison River streamflow with the estimated flow that would have occurred without any development were comparable to those estimated for the runoff period using the three development periods (Table 2; Table A7). However, estimated changes for the remainder of the year differed substantially. This is undoubtedly due in large part to the irrigation diversions that were already in place when stream gaging began. The water diverted for irrigation would be a small portion of the available water during runoff, but would be a large portion of streamflow during summer months. Thus the 'early development' streamflows were already less than natural flows.

The effect of the Aspinall Unit on runoff was estimated by comparing the change in streamflow from the middle-development period to the post-Aspinall period. Mean-monthly streamflow declined about 1.4% in April, 25.1% in May, and 32.2% in June (Table 3). Streamflow during the remainder of the year has increased, particularly during the winter when average flows are more than 100% greater than pre-Aspinall flows (Table A5). Gunnison River mean-monthly flows have declined an average of 1,864 cfs in May and 2,326 cfs in June

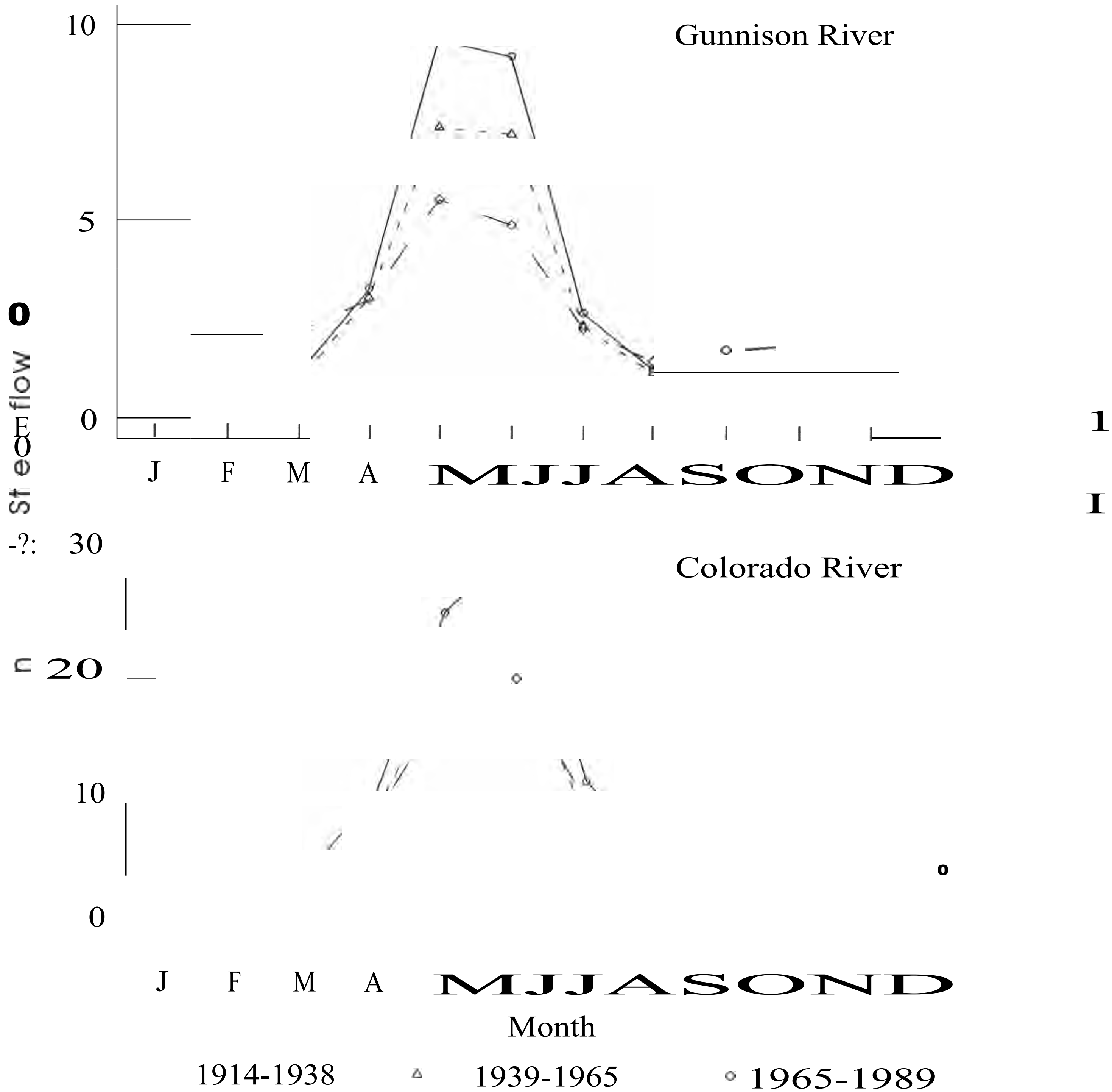

Figure 7. Mean-monthly streamflow in the Gunnison (upper) and Colorado (lower) rivers for three periods (early development [1914-1938], middle development [1939-1965], and post-Aspinall development [1966-1988]).

Table 1. Mean maximum-annual discharge (average of the highest mean-daily flow for the year) for the Gunnison (Whitewater gage) and Colorado (Cisco gage) rivers for three time periods: early development, middle development, and post Aspinall development.

River	Time Period	Mean	Standard Error	Minimum	Maximum	Percent Change: Period to Period	Percent Change: Early to Post
Colorado	Early	45,870	3,158	16,800	73,200		
	Middle	35,425	2,827	12,100	63,400	-23	
	Post	28,873	3,089	4,970	69,500	-18	-37
Gunnison	Early	17,116	1,529	3,735	35,175		
	Middle	13,673	1,301	3,170	27,340	-20	
	Post	9,003	1,090	1,020	23,140	-34	-47

Table 2. Comparison of streamflow changes in the Gunnison River (Whitewater gage) estimated using two techniques. 1. Comparison of actual streamflows with estimated flows that would have occurred without any water development (1952-1965 and 1966-1983). 2. Comparison of actual streamflows during three water development phases in the Gunnison River: early development (1917-1938), middle development (1939-1965), and post Aspinall development (1966-1988).

Month	Percent change in mean-monthly streamflow: Actual flow/ estimated flow (1952-1965)	Middle period/ early period	Actual flow/ estimated flow (1965-1983)	Post Aspinall/ early period
APR	- 16.1	- 6.6	- 21.8	- 8.0
MAY	- 23.6	- 23.2	- 45.1	- 42.5
JUN	- 25.4	- 21.8	- 52.9	- 46.9
JUL	- 33.6	- 12.1	- 47.6	- 14.4
AUG	- 40.1	- 7.3	- 27.7	+ 14.0

Table 3. Percent decline of mean-monthly streamflow in the Gunnison (Whitewater gage) and Colorado (Cisco gage) rivers during spring runoff attributable to the Aspinall Unit. (Change from middle-development period to post-Aspinall period.)

	Gunnison River		Colorado River		
Month	Percent change	Change in CFS	Percent change	Change in CFS	Percent of change in Colorado River due to Aspinall
April	- 1.4	43.8	- 3.7	305.2	14.4
May	-25.1	1,864.1	-12.8	2,477.3	75.2
June	-32.2	2,326.7	-12.8	2,778.1	84.0
July	- 2.6	62.6	+ 8.6	699.4	

(Table 3). Mean-monthly Colorado River flows have declined 2,477 and 2,778 cfs for the same months. Because changes in Gunnison River flow directly affect Colorado River flow, the Aspinall Unit is responsible for 75 to 85% of the decrease in average spring runoff since 1966 for the Colorado River at Cisco (Table 3).

EFFECT OF CHANGES CAUSED BY THE ASPINALL UNIT ON THE ENDANGERED FISHES

Water Temperature

The Aspinall Unit reduced the temperature of the Gunnison River within historic range of Colorado squawfish and razorback sucker. This temperature reduction probably did not affect adult habitat, but may have affected maturation of adult fish or spawning success--particularly of Colorado squawfish. Pre-Aspinall temperatures in the lower Gunnison River were already marginal for Colorado squawfish reproduction, but construction of the Aspinall Unit reduced them further. Wiltzius (1978) suggested that construction of the

Aspinall Unit did not adversely affect the endangered fishes in the Gunnison River because their numbers had already been reduced by a variety of factors--particularly the blockage of movement into the Gunnison River by the Redlands Diversion Dam. However, there is a remnant population of Colorado squawfish in the Gunnison River above the Redlands Dam. It is not known whether the fish moved above the diversion dam during the relatively short periods (due to dam maintenance or other activities) when upstream movement is possible or whether they were spawned above the diversion. If spawning is being attempted in the Gunnison River, the reduced temperatures (even though the reduction is small) would decrease the probability that it would be successful. Further, the reduced temperature would decrease the probability of success if future reintroduction efforts are directed at the Gunnison River.

Colorado River temperatures are essentially unchanged by the Aspinall Unit. Therefore, water temperature changes as a result of the Aspinall Unit probably did not affect the endangered fishes in the mainstem Colorado River.

Sediment Load

It is unknown how the reduced sediment load has affected the endangered fishes. Reduced sediments have affected the Gunnison River (e.g. the armored bottom in many areas [Sanford and Ward 1983]), but because the fish were already greatly reduced before Aspinall was completed, it is unlikely that the sediment changes caused their decline. However, the changed substrate may affect the success of future reintroductions.

The primary effect of reduced sediment levels involves the maintenance of backwaters in the lower Colorado River, an important habitat for young-of-the-year Colorado squawfish. However, the sediment load of the Colorado River remains high (Thompson 1984), and it is unknown whether reduced sediment levels as a result of the Aspinall Unit have affected the endangered fishes in the Colorado River.

Streamflow

The most important change resulting from construction of the Aspinall Unit has been the reduction of spring flows in the Gunnison and Colorado rivers. Spring flow is the most important annual event that shapes the channel, and thus the habitat of the two rivers. High spring flows create and maintain the braided channels that provide a variety of important habitats for the endangered fishes. Reduction of high spring flows allows the river to gradually simplify its channel--side channels and backwaters fill with silt and become unusable by the native fishes, sand bars are invaded by tamarisk which stabilizes them and makes them resistant to erosion, and gravel-cobble substrates become armored or imbedded in silt which reduces their utility as spawning substrate.

Colorado squawfish

Osmundson and Kaeding (1990) showed that radiotagged Colorado squawfish selected complex-habitat areas over simple-habitat areas in the upper Colorado River. They divided their 33-mile study area into 0.4-mile segments and categorized each segment as either complex or simple depending upon whether islands, backwaters, or side channels were present or absent. Their study area contained equal numbers of simple and complex segments, but radiotagged Colorado squawfish were most often located in complex-channel segments. Of a total of 428 observations of radiotagged Colorado squawfish, 85% of spring locations, 71% of summer locations, and 63% of winter locations were in complex-channel segments (Osmundson and Kaeding 1990). The complex segments provide a greater diversity of habitats for Colorado squawfish to utilize for feeding, resting, and other activities. High spring flows are important in maintaining these areas.

High spring flows are also important to successful reproduction of Colorado squawfish. McAda and Kaeding (1989) reported higher reproductive success in the Colorado River during years of moderately high flow. The Fish and Wildlife Service conducted fall surveys to determine relative abundance of young-of-the-year (YOY) Colorado squawfish in the Colorado River from 1982 to 1985 (Archer et al. 1985). Beginning in 1986, similar surveys were conducted by the states of Utah and Colorado as part of the Interagency Standardized Monitoring Program (ISMP). ISMP divided the river into two reaches (1, RM 0-110 and 2, RM 140-170), based on the known distribution of Colorado squawfish (Archer et al. 1985). McAda and Kaeding (1989) used the FWS and ISMP data to compare relative abundance of YOY Colorado squawfish in fall with maximum-annual discharge (mean-daily flow on the highest day) the previous spring (Figure 8). They found a parabolic relation in reach 1--the highest relative abundance of YOY Colorado squawfish occurred in 1985 and 1986 when spring flows peaked at 32,800 and 38,200 cfs at the stateline gage (peak flows at Cisco were 34,100 and 43,200 cfs). Relative abundance was lower in years that had lower and substantially higher peak discharges (Figure 8). McAda and Kaeding (1989) found no clear relation in reach 2 for the years they studied, but Osmundson and Kaeding (1990) showed a positive relation between relative abundance of age-0 Colorado squawfish and maximum-annual discharge for about the same reach during 1986 to 1989. It is not yet clear whether spring runoff itself or another variable closely related to spring runoff is responsible for

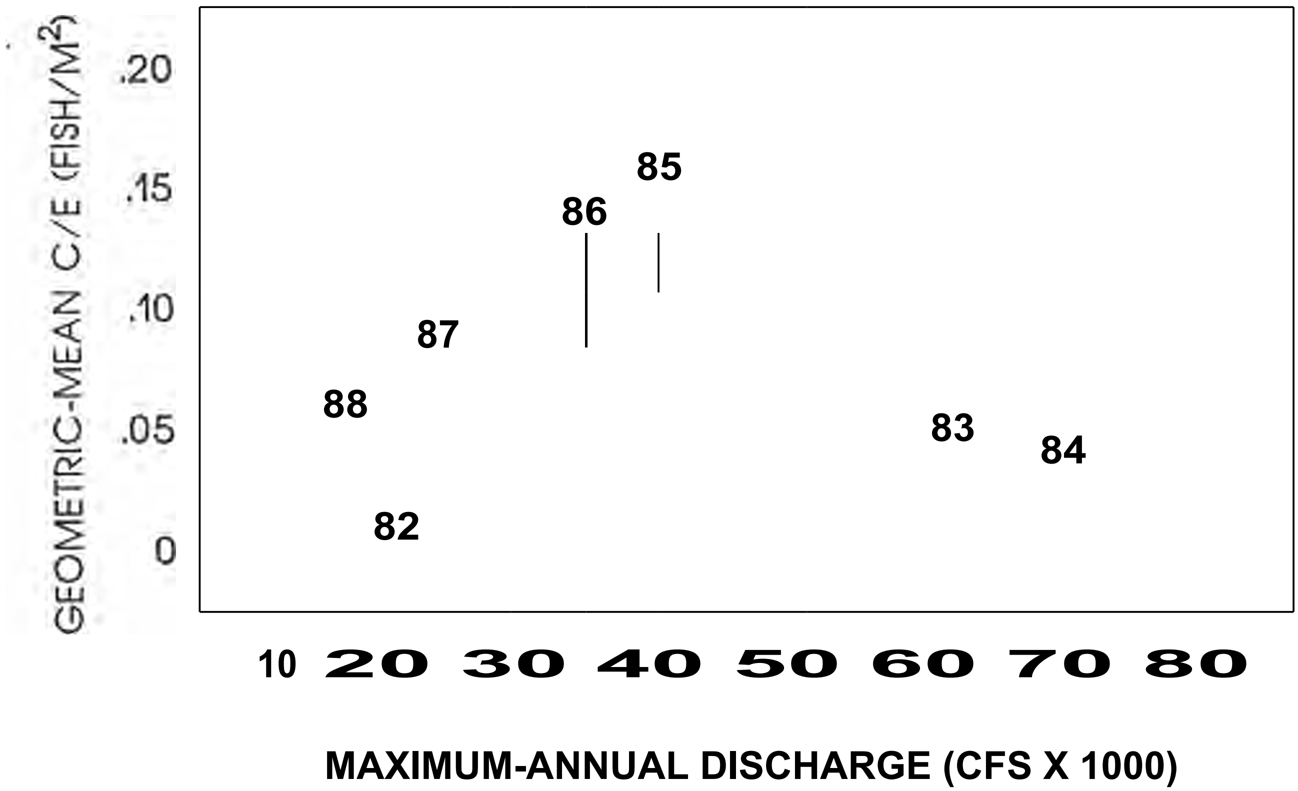

Figure 8. Plot of geometric-mean catch per effort (C/E) versus maximum-annual discharge (stateline gage) for post-larval Colorado squawfish collected in the Colorado River between river miles 0 and 110 during October, 1982-1988. Lines indicate ± 1 standard error; numbers indicate year of collection. Excerpted from McAda and Kaeding (1989).

the observed differences: none-the-less, spring runoff is obviously important to successful reproduction by Colorado squawfish.

Numerous investigators have found relations between maximum-annual discharge and the relative abundance of other fish species (McAda and Kaeding 1989; Osmundson and Kaeding 1989, 1990; Valdez 1990). Considerable variation exists, but in general, relative abundance of young-of-the-year of native species is positively correlated with maximum-annual discharge and relative abundance of introduced species is negatively correlated with the same value. Osmundson and Kaeding (1989) observed that fathead minnow Pimephales promelas, red shiner Notropis lutrensis, and sand shiner N. stramineus developed large populations in the Colorado River near Grand Junction after three consecutive years of low spring runoff. McAda and Kaeding (1989) and Valdez (1990) observed the same phenomenon for the Colorado River in Utah for the same species over the same period. High spring runoff may be important in reducing the numbers of these introduced fishes. Numerous investigators have hypothesized that introduced species have negatively affected Colorado squawfish through predation or competition (e.g. Karp and Tyus 1990 and references therein). Therefore, reducing the population size of introduced species through high spring flows is desirable. Minckley and Meffe (1987) reported that some introduced species were eliminated from some Arizona streams after high runoff events. Introduced species will never be eliminated from the Colorado River by high runoff, but regular high-runoff events may play a role in limiting the numbers of undesirable species.

Razorback sucker

High spring runoff may also be important to successful reproduction of razorback sucker. Although spawning is being attempted, recruitment to the adult population is very low or nonexistent in the Upper Colorado River Basin (McAda and Wydoski 1980; Tyus 1987). Razorback suckers spawn in spring (McAda and Wydoski 1980; Tyus 1987; Osmundson and Kaeding 1990), during the period when streamflow is at or near the annual maximum. Water temperature during spring runoff is relatively low in the main channel (often less than 15 °C, USGS records), yet Marsh (1985) reported the highest hatching success for razorback sucker eggs at 20 °C. Hamman (1985) and Inslee (1982) also believed the optimum temperature for reproduction was at or near 20 °C, a temperature not reached in the main channel of the Colorado River for a month or more after spawning apparently occurs. Osmundson and Kaeding (1990) reconciled this apparent conflict by hypothesizing that razorbacks historically spawned in flooded areas out of the main channel. These flooded areas are warmed by sunlight and ambient air temperature, and are often much warmer than the main channel. Osmundson and Kaeding (1990) reported temperatures of 22 °C in off-channel habitats when main-channel temperature was 13 °C. If their hypothesis is correct, reduced spring flows could account for the lack of reproductive success by razorback sucker. Unfortunately, the effect of reduced spring runoff has been compounded by dike building and channelization which has reduced the number of lowland areas available for flooding, and by the occurrence of large numbers of introduced fishes in the remaining flooded habitats. Predation on razorback sucker eggs and larvae by introduced fishes may also contribute to reproductive failure (Minckley 1983; Tyus 1987). Suitable habitat for reintroduction of razorbacks into the Gunnison River exists near Delta (Wick, personal communication) if adequate streamflows can be restored.

<u>Humpback</u> chub

Humpback chub spawn during spring runoff (Valdez and Clemmer 1982; Kaeding et al. 1990), so it is likely that runoff level affects reproductive success of the species. However, the relationship has not yet been examined. Eight years of river-wide larval data are available and could be examined to estimate the relative abundance of young-of-the year humpback chub. Reliable identification of larval humpback chub was not possible until recently when Muth (1990) completed a key describing larvae of bonytail, roundtail chub, and humpback chub. However, it is not clear whether the river-wide data will be adequate to evaluate the reproductive success of humpback chub. Their restriction to specific river reaches may require more intensive investigation of the areas where they are most common--Black Rocks, Westwater Canyon, and Cataract Canyon. It is also likely that spring runoff is important in maintaining these unique habitats. Valdez and Clemmer (1982) suggested that runoff may contribute to reproductive isolation between humpback and roundtail chubs; however, Kaeding et al. (1990) felt that other isolating mechanisms may be more important. Further investigation into isolating mechanisms may be necessary.

Bonytail

Bonytail are so rare that it is impossible to estimate the effect reduced spring runoff may have had on this species. However, like the other native species of the Colorado River Basin, bonytail are accustomed to regular, high-runoff levels and the reduced frequency of these events was probably detrimental to the species. Reduced spring runoff could affect any reintroduction program attempted for the species.

SUMMARY

Water Temperature

Water temperature is essentially unchanged in the Colorado River, but reduced somewhat in the Gunnison River within the historic range of razorback sucker and Colorado squawfish. The reduced temperature could affect spawning success of either of the two fishes if remnant populations still exist there. The success of future reintroductions of either species might be improved by relatively minor temperature increases in the Gunnison River.

Sediment Load

The sediment loads of the Gunnison and Colorado rivers have been reduced by construction of the Aspinall Unit. However, both rivers still carry heavy sediment loads and it is unclear whether the change has affected the endangered fishes.

Streamflow

The greatest change caused by construction of the Aspinall Unit has been the reduction of spring runoff. Mean-monthly streamflow of the Gunnison River was reduced by 1,864 cfs (25.1%) in May and 2,326 cfs (32.2%) in June. These flow changes caused 75% and 85% of the reduced streamflow in the Colorado River for the same months. High spring runoff is important for maintenance of complex river channels which provide diversified habitats for the endangered fishes. High spring runoff is also important to the reproductive success of Colorado squawfish and for population control of undesirable species. High spring runoff still occurs, but the frequency of the higher runoff levels has been reduced. Although the relationships are still unknown, it is very likely that the amount of spring runoff is an important variable affecting the reproductive success of razorback sucker and humpback chub as well.

STUDY PLAN

The Aspinall Unit and other Bureau of Reclamation projects have reduced the volume of spring runoff in the Gunnison and Colorado rivers. Spring runoff is the most important variable in determining the physical environment of the river during the coming year. This report discusses several ways in which this altered streamflow may have effected the endangered fishes. The purpose of this section is to propose hypotheses and studies to evaluate these possible effects. An important component will be to provide test flows from the Aspinall Unit to facilitate the studies. Because the largest change resulting from the construction and operation of Aspinall (and other Bureau projects) has been to alter the flow regime, the test flows should more closely mimic the natural hydrograph of the Gunnison River (i.e. higher spring flows, and lower fall and winter flows). The unallocated water currently stored in Blue Mesa Reservoir should be used to supply water for the study.

The evaluation of the effects of the Aspinall Unit will involve a series of studies, conducted by different organizations, but closely coordinated by the Fish and Wildlife Service and the Bureau of Reclamation. The evaluation will involve five years; however, many of the individual studies can be completed more quickly. The five-year time frame should be sufficient to allow for unforseen problems that could delay completion of individual studies. Also, it is likely that the proposed studies may identify additional questions to be asked. Because of the large variation in spring flows requested, the ability to release the higher spring flows will be limited in some years because of low snowpack or low storage. Because of this uncertainty, we may not be able to predict more than a few months in advance what the releases for a given year will be. The amount of spring runoff to be released for the study will vary among years, but the test flows should provide a peak in the Gunnison River (measured at the USGS gage near Grand Junction) of between 2,000 and 5,000 cfs for one year, between 5,000 and 10,000 cfs for one year, above 12,000 cfs for two years, and above 15,000 for one year. Runoff should increase and decrease in a gradual, natural manner and should peak between May 15 and June 15. The peak should be timed to correspond as closely as possible with the peak of the Colorado River. Test flows (mean-monthly flows) for the remainder of the year are as follows:

Jan	Feb	Mar	Apr	May	Jun
700	700	700	900	3,000	2,000
900	900	1,000	1,500	4,000	3,500
1,100	1,100	1,300	3,000	6,000	5,000
1,300	1,300	1,800	5,000	8,000	6,500
1,700	1,700	2,200	7,000	10,000	8,000

Jul	Aug	Sep	Oct	Nov	Dec
1,000	1,000	1,000	700	700	700
1,400	1,300	1,000	900	900	900
1,900	1,700	1,300	1,100	1,100	1,100
2,500	2,100	1,600	1,300	1,300	1,300
3,000	2,500	2,000	1,500	1,500	1,500
3,000	2,500	2,000	1,500	1,500	1,500

The proposed test flows have all occurred during the last ten years. However, the test flows represent a range that more closely represents the natural hydrograph of the river--with the requested fall, winter, and summer flows taken from the lower end of the observed range and the requested spring flows on the high end of the recent range. As mentioned above, flows will be measured at the USGS gage near Grand Junction, so releases from Aspinall should be coordinated with flows in other streams. The test flows are arranged from lowest to highest flow for each month, but this does not necessarily mean that each line represents the flow pattern for one year of the study. By necessity, the lowest winter flows will probably occur with the highest spring flows and conversely the highest winter flows will probably occur with the lowest spring flows.

In general, the test flows for all months apply to all the hypotheses. However, certain hypotheses are oriented toward more specific flows and time periods. Hypotheses 1, 2, 3, 8, and 9 are specifically oriented toward spring flows, but year-around flows also apply. The remaining hypotheses are directed toward flows that occur throughout the year--naturally spring flows are important here as well. Hypotheses 1, 2, 3, 7, and 10 are oriented towards flows in the Colorado River, but Gunnison River flows are an important component. Hypotheses 4, 5, and 6 are oriented toward flows in the Gunnison River, and flows in both rivers are equally important to hypotheses 8 and 9. For these reasons, it is important that the full range of requested flows occur during the five years of the study.

The hypotheses to be tested are arranged in groups that are closely related to each other and that could be tested with similar or the same studies. However, all of the hypotheses are related to some degree and all studies should be closely coordinated to eliminate redundancy and to ensure maximum information gain during the study period. The suggested methods provide guidelines for researcher's proposals. However, researchers are encouraged to expand upon these ideas where appropriate. It is very possible that additional (or more specific) hypotheses will evolve during the course of the studies. It will be very important to incorporate the additional questions into the study as soon as possible.

Hypothesis 1: Reproductive success of Colorado squawfish in the Colorado River is greatest during years with maximum-annual discharges of 30,000 to 40,000 cfs (measured at the Cisco stream gage). Reproductive success is **reduced in years with higher or lower peak discharges.**

Hypothesis 2: High spring flows reduce the survival of age-0 Colorado squawfish by reducing the growing season and thus the size of the fish entering their first winter.

Hypothesis 3: High spring flows reduce non-native fish populations.

The Interagency Standardized Monitoring Program samples for age-0 Colorado squawfish every fall. The mean catch-per-unit-effort of these samples measures the variation in abundance of this size class among years and is a useful indicator of the annual reproductive success of the species. As shown in this report, the abundance of age-0 Colorado squawfish in the Colorado River is related to the maximum-annual streamflow that occurred the previous spring. Increased runoff in the Gunnison River (and thus the Colorado River) and the continuation of the monitoring program will be an effective test of this relationship. Survival of the young Colorado squawfish is very important in determining the total number of fish that recruit to the adult population. Investigations should not only consider what environmental conditions result in the greatest number of young fish, but what conditions result in the highest survival of the fish that are produced. Many factors (i.e. length of fish at the end of their first growing season or winter conditions) can influence the survival of the small fish. Studies to evaluate the over-winter survival of these fish have been conducted for the last three years (scope of work entitled Flow effects on young-of-the-year Colorado squawfish). These studies will be evaluated this year. Over-winter mortality is undoubtedly important in at least some years, and should continue to be investigated. In addition, there may be a general downstream movement pattern of small Colorado squawfish that could carry them into Lake Powell and further reduce their chance of survival. This movement pattern should also be evaluated.

Reproductive success should also be measured by sampling for larvae. Several years of river wide, larval dip-net samples have already been collected--this sampling should continue. However, the dip-net samples should be supplemented by drift net sampling at several strategic locations. Current data indicate that Colorado squawfish spawn at many scattered locations in the Colorado River between Grand Junction, Colorado and Lake Powell, Utah. However, the majority of larvae and young-of-the-year Colorado squawfish are found in the lower 100 miles of river. The larval sampling program should attempt to determine where these larvae are produced. The Larval Fish Laboratory will be writing a discussion paper on larval sampling techniques and interpretation of results (scope of work entitled Position paper on studies to evaluate movements of Colorado squawfish larvae throughout the Upper Colorado River Basin). The results of their analysis will be important to developing an appropriate sampling design.

Non-native fishes are also counted during the fall seining done by the Interagency Standardized Monitoring Program. However, nonnative fish are only counted in one-quarter of the seine hauls taken. Evaluation of the size of the non-native fish community should include counting all fish in all seine hauls and categorizing them by size class--at least young of the year and adult. This additional work has already begun under the scope of work entitled Flow effects on young-of-the-year Colorado squawfish. The majority of these fish are preserved for identification in the laboratory and are available for additional investigations.

Data analysis should involve all environmental variables that could affect reproductive success and survival of Colorado squawfish and the non-native species. These variables should include (but not necessarily be limited to) spring flow, summer flow, winter flow, habitat availability, water temperature, and abundance of other species.

Hypothesis 4: The Gunnison River above Redlands Diversion contains a small, but viable Colorado squawfish population.

Hypothesis 5: Providing passage around the Redlands Diversion will benefit Colorado squawfish in both the Colorado and Gunnison rivers.

Valdez et al. (1982a) collected eight adult-size Colorado squawfish from the Gunnison River above Redlands Diversion during their 1979 to 1981 study. Wick (personal communication) collected several adult Colorado squawfish from the Gunnison River in autumn 1982. The river has received very little sampling effort since that time. A thorough evaluation of the present fish community is necessary before management decisions about the Gunnison River can be made. The survey of the Gunnison River should include the section from Delta downstream to the Redlands Diversion (about 55 river miles) and should encompass two full field seasons. The study should utilize the same river strata, the same gear types, and the same systematic sampling schedule used by Valdez et al. (1982a). The study should also include extra sampling at locations where Colorado squawfish were previously captured, twice-monthly systematic sampling of the larval fish community, and a fall young-of-the-year survey, similar to that conducted as part of the Interagency Standardized Monitoring Program.

The Redlands Diversion prevents access by Colorado squawfish and razorback sucker to 55 miles of apparently useable habitat. Proposals exist to provide access to the Gunnison River by either removing the diversion structure or building a fish-passage facility to move fish over the structure. Although Colorado squawfish congregate below the structure at certain times (Osmundson and Kaeding 1990), it is unknown whether the fish would have moved further into the Gunnison River, and if so, how far they would have gone. To examine the potential use of the Gunnison River by Colorado squawfish, a maximum of four fish per year (if available) should be collected from the Redlands Diversion pool, implanted with radio transmitters, and moved upstream over the dam. In addition, any Colorado squawfish collected in the Gunnison River during other studies (up to a maximum of four per year) should also be implanted with radio transmitters and monitored in conjunction with the Colorado River fish. The radiotelemetry study should be conducted for three years and should use long-term transmitters if possible. Additional fish should be implanted every year. The fish should be monitored weekly from April through October; bimonthly or monthly for the remainder of the year. This study could be conducted in conjunction with the Gunnison River habitat study to document habitat use by the radio-tagged Colorado squawfish.

Current efforts to explore removal of the Redlands Diversion Dam should continue.

Hypothesis 6: The Gunnison River contains habitat suitable for reintroducing razorback sucker, augmenting the Colorado squawfish population, and establishing a new population of humpback chub.

Hypothesis 7: Increased flows in the Gunnison River **will** improve the success of razorback sucker augmentation in the Colorado River.

The Gunnison River once contained populations of razorback sucker and Colorado squawfish; these populations are now very low or extirpated. The test flows from the Aspinall Unit have the potential to improve the available habitat such that razorback sucker and Colorado squawfish can reoccupy the lower 55 miles of the river. Canyon habitats suitable for introduction of humpback chub may also be available. However, the relative availability of different habitat types is unknown. The available habitat needs to be quantified in relation to the test flows released over the course of a year. Emphasis should be placed on the relative availability of flooded backwaters and other quiet water areas during high-flow periods and on general habitats available during base-flow periods.

Investigation of management opportunities to improve or manipulate habitat to benefit endangered fish should begin after the general distribution of the available habitats is identified. Evaluation of the feasibility of introducing one or more of the endangered species into the Gunnison River or augmentation of the razorback sucker population in the Colorado River should accompany investigation of habitat management opportunities. The razorback sucker population is currently so low that investigations into its habitat requirements are impossible. However, augmenting its current population would allow investigations into its habitat requirements as well as providing useful information that could be applied to future augmentation programs for the other rare species.

Hypothesis 8: Higher flows will increase flooded areas in spring for adult fish use in both the Colorado and **Gunnison** rivers and will improve quality of young-of-the-year habitat in the Colorado River.

High spring flows have an important influence on riverine habitat for the coming year. Documentation of the amount of flooded-bottomland habita created by higher spring flows will be important in determining the level of spring runoff that will create the greatest amount of habitat. Monitoring will also be important in examining the relationship between spring runoff and number and area of backwaters available the following fall. The specific techniques to accomplish this task need further development but a combination of ground truthing and aerial videography would be appropriate. The study should include both the Gunnison and Colorado rivers. Habitat should be mapped at peak flow and at several flows between high flow and base flow for the year. Mapping should occur over several years to ensure that a complete range of flows is mapped. Sites should be selected to cover the complete range of habitats (i.e. flooded areas for adults, backwater areas for young of the year). Some sites should be selected based on known importance to endangered fishes and others should be selected randomly to ensure that the complete range of available habitats are included.

Hypothesis 9: Higher spring flows from the Aspinall Unit will improve the ability of the Gunnison and Colorado rivers to clean spawning substrate, to maintain sand and silt substrates in nursery areas, and to maintain natural channel characteristics.

Thompson (1984) showed that the Aspinall Unit reduced the sediment load of the Colorado River. However, the effect of reduced sediment levels on riverine habitat is unknown. We donot know what duration and level of flow is necessary to clean the cobble and rubble areas believed important for spawning. The ability of the Gunnison and Colorado rivers to move substrates of various sizes should be investigated. Also, level and duration of flows necessary to maintain natural channel chacteristics should be investigated. Flow changes have reduced the rivers' ability to maintain channel width, but this change has been compounded by construction of dikes in populated areas and encroachment of tamerisk on streambanks and islands in non-populated areas. The relative contribution of these factors (as well as others that may be important) should be evaluated and management suggestions developed.

Hypothesis 10: Reproductive success of humpback chub in Black Rocks and Westwater Canyon will be enhanced by high spring flows from the Gunnison River. Survival of young chubs will improve under a more natural flow regime.

Although relationships are unknown at present, it is very likely that reproductive success of humpback chubs is related to spring runoff, or at least to conditions created by spring runoff. The reproductive success of humpback chubs should be monitored. This will require more studies than currently done under ISMP (although these additional studies should be closely coordinated with ISMP). In addition, the reproductive isolating mechanism(s) that may be operating between roundtail and humpback chubs should be further investigated.

More information about habitat requirements should be developed, particularly for spawning and for young-of-the-year and subadult fish. It is generally believed that adult habitat within Black Rocks is relatively unaffected by streamflow. We need to validate this relationship as well as determine the relationship for Westwater Canyon. Further, we need to determine what habitats small humpback chubs occupy and how this habitat is affected by changes in streamflow. Efforts in Black Rocks and Westwater Canyon should concentrate on spawning requirements as well as habitat for young of the year and subadult humpback chubs.

Estimated Time Schedule

	Year				
	1	2	3	4	5
Hypothesis 1					
Reproductive Success[a]	X	X	X	X	X
Larval Sampling[b]	X	X	X	X	X
Hypothesis 2					
Over-winter Survival[b]	X	X	X	X	X
Hypothesis 3					
Non-native fish numbers[a]	X	X	X	X	X
Hypothesis 4					
Fish Survey	X	X			
Hypothesis 5					
Radiotagging	X	X			
Evaluate Removal	X				
Hypothesis 6					
Habitat Evaluation	X	X			
Management Evaluation			X	X	
Hypothesis 7					
Razorback Sucker Augmentation		X	X	X	X
Hypothesis 8					
Colorado River Habitat		X	X		
Hypothesis 9					
Sediment/Channel Morphology Study				X	X
Hypothesis 10					
Humpback Chub		X	X	X	X

[a]Ongoing study.
[b]ongoing study; methodology and results should be reevaluated.

REFERENCES

Archer, D. L., L. R. Kaeding, B. D. Burdick, and C. W. McAda. 1985. A study of the endangered fishes of the upper Colorado River. Final Report. U.S. Fish and Wildlife Service, Colorado River Fishery Project. Grand Junction, Colorado. 134 pp.

Chamberlain, T. K. 1946. Fishes; particularly the suckers, Catostomidae, of the Colorado River drainage and of the Arkansas River drainage, in relation to the Gunnison-Arkansas transmountain diversion. Typewritten letter of February 24, 1946 from U. S. Fish and Wildlife Service, College Station, Texas. 8 pp. (not seen, cited in Wiltzius 1978)

Ellis, M. M. 1914. Fishes of Colorado. University of Colorado Studies, Boulder, Colorado. 11(1):5-132.

Elliott, J. G., and K. L. DeFeyter. 1986. Sediment-data sources and estimated annual suspended-sediment loads of rivers and streams in Colorado. U.S. Geological Survey, Water-resources investigations report 86-4344. Denver, Colorado.

HDR Engineering, Inc. 1989. Upper Gunnison-Uncompahgre basin, Phase 1-feasibility study. Final report to The Colorado Water Resources and Power Development Authority. HDR Engineering, Inc., Denver, Colorado.

Hamman, R.L. 1985. Induced spawning of hatchery-reared razorback sucker. The Progressive Fish Culturist 47:187-189.

Holden, P.B., and C.L. Stalnaker. 1970. Systematic studies of the cyprinid genus Gila in the upper Colorado River basin. Copeia 1970:409-420.

Holden, P.B., and C.L. Stalnaker. 1975. Distribution and abundance of mainstream fishes of the middle and upper Colorado River basins, 1967-1973. Transactions of the American Fisheries Society 104:217-231.

Inslee, T.D. 1982. Spawning of razorback suckers. Pages 145-157 in W. H. Miller, J.J. Valentine, D.L. Archer, H.M. Tyus, R.A. Valdez, and L. Kaeding, editors. Colorado River Fishery Project. Part 3 - Contracted studies. U.S. Bureau of Reclamation, Salt Lake City, Utah.

Jordan, D. S. 1891. Report of exploration in Colorado and Utah during the summer of 1889, with an account of the fishes found in each of the river basins examined. Bulletin of the United States Fish Commission 9:1-40.

Kaeding, L. R., B. D. Burdick, P. A. Schrader, and C. W. McAda. 1990. Temporal and spatial relations between the spawning of humpback chub and roundtail chub in the upper Colorado River. Transactions of the American Fisheries Society 119:135-144.

Kaeding, L. R., B. D. Burdick, P. A. Schrader, and W. R. Noonan. 1986. Recent capture of a bonytail (Gila elegans) and observations on this nearly extinct cyprinid from the Colorado River. Copeia 1986:1021-1023.

Karp, C. A., and H. M. Tyus. 1990. Behavioral interactions between young Colorado squawfish and six fish species. Copeia 1990:25-34.

Kidd, G. T. 1977. An investigation of endangered and threatened fish species in the upper Colorado River as related to Bureau of Reclamation projects. Final Report to Bureau of Reclamation, Northwest Fishery Research, Clifton, Colorado.

Kinnear, B.S. 1967. Fishes of Black Canyon. Master's thesis, Colorado State University, Fort Collins.

Marsh, P. C. 1985. Effect of incubation temperature on survival of embryos of native Colorado River fishes. Southwestern Naturalist 30:129-140.

McAda, C. W., and L. R. Kaeding. 1989. Relations between maximum-annual river discharge and the relative abundance of age-0 Colorado squawfish and other fishes in the upper Colorado River. Final report. U.S. Fish and Wildlife Service, Colorado River Fisher Project. Grand Junction, Colorado. 25pp.

McAda, C. W., and R. S. Wydoski. 1980. The razorback sucker, Xyrauchen texanus, in the upper Colorado River basin, 1974-76. U.S. Fish and Wildlife Service Technical Paper 99.

Miller, R. R. 1946. Gila cypha, a remarkable new species of cyprinid fish from the Colorado River in Grand Canyon, Arizona. Journal of the Washington Academy of Sciences 36:409-413.

Miller, R. R. 1961. Man and the changing fish fauna of the American Southwest. Michigan Academy of Science, Arts and Letters 46:365-404.

Minckley, W. L., and J. E. Deacon. 1968. Southwestern fishes and the enigma of "endangered species." Science 159:1424-1432.

Minckley, W. L., and G. K. Meffe. 1987. Differential selection by flooding in stream fish communities of the arid American southwest. Pages 93-104 in W. J. Matthews and D. C. Heins, editors. Community and evolutionary ecology in North American stream fishes. University of Oklahoma Press, Norman.

Muth, R. T. 1990. Ontogeny and taxonomy of humpback chub, bonytail, and roundtail chub larvae and early juveniles. Doctoral disseratation, Colorado State University, Fort Collins.

Osmundson, D. B., and L. R. Kaeding. 1989. Studies of Colorado squawfish and razorback sucker use of the "15-mile reach" of the upper Colorado River as part of conservation measures for the Green Mountain and Ruedi Reservoir water sales. Final report. Colorado River Fishery Project, U. S. Fish and Wildlife Service, Grand Junction, Colorado.

Osmundson, D. B., and L. R. Kaeding. 1990. Flow recommendations for maintenance and enhancement of rare fish habitat in the 15-mile reach during Oct-June. Draft report. U.S. Fish and Wildlife Service, Colorado River Fishery Project, Grand Junction, Colorado.

Seethaler, K. 1978. Life history and ecology of the Colorado squawfish (Ptychocheilus lucius) in the upper Colorado River basin. Master's thesis. Utah State University, Logan.

Stanford, J. A., and J. V. Ward. 1983. The effects of mainstream dams on physicochemistry of the Gunnison River, Colorado. In V. D. Adams and V. A. Lamarra, editors. Aquatic resources management of the Colorado River Ecosystem. Ann Arbor Science Publishers, Ann Arbor, Michigan.

Theurer, F. D., K. A. Voos, and W. J. Miller. 1984. Instream water temperature model. Instream Flow Information Paper 16. Cooperative Instream Flow Aquatic System Group. U. S. Fish and Wildlife Service. Fort Collins, Colorado.

Thompson, J. M. 1989. The role of size, condition, and lipid content in the overwinter survival of age-0 Colorado squawfish. Master's thesis, Colorado State University, Fort Collins.

Thompson, K. R. 1984. Annual suspended-sediment loads in the Colorado River near Cisco, Utah, 1930-1982. U.S. Geological Survey, Water-resources investigations report 85-4011. Salt Lake City, Utah.

Tyus, H. M. 1987. Distribution, reproduction, and habitat use of the razorback sucker in the Green River, Utah, 1979-1986. Transactions of the American Fisheries Society 116:111-116.

USBR (U. S. Bureau of Reclamation). 1978. Unpublished supporting data, Colorado River simulation system--natural flow development for the Gunnison River at Grand Junction. Salt Lake City, Utah. 9-90.

Valdez, R. A. 1990. The endangered fish of Cataract Canyon. Final report to Bureau of Reclamation, Salt Lake City, Utah. Contract No. 6-CS-40-03980, Fisheries Biology and Rafting. Bio/West report no. 134-3.

Valdez, R. A., and G. H. Clemmer. 1982. Life history and prospects for recovery of the humpback chub and bonytail chub. Pages 109-119 in W. H. Miller, H. M. Tyus, and C. A. Carlson, eds. Fishes of the upper Colorado River system: present and future. Western Division, American Fisheries Society, Bethesda, Maryland.

Valdez, R., P. Mangan, M. McInerny, and R. P. Smith. 1982a. Tributary report: Fishery investigations of the Gunnison and Dolores rivers. Pages 321 to 362 in W. H. Miller et al., editors. Colorado River Fishery Project Final Report; Part Two, Field Studies. U. S. Fish and Wildlife Service and Bureau of Reclamation. Salt Lake City, Utah.

Valdez, R., P. Mangan, R. Smith, and B. Nilson. 1982b. Upper Colorado River Investigation (Rifle, Colorado to Lake Powell, Utah). Pages 101-279 in W. H. Miller et al., editors. Colorado River Fishery Project Final Report; Part Two, Field Studies. U. S. Fish and Wildlife Service and Bureau of Reclamation. Salt Lake City, Utah.

Vanicek, C.D., R.H. Kramer, and D.R. Franklin. 1970. Distribution of Green River fishes in Utah and Colorado following closure of Flaming Gorge Dam. Southwestern Naturalist 14:297-315.

Wiltzius, W.J. 1978. Some factors historically affecting the distribution and abundance of fishes in the Gunnison River. Final report to U.S. Bureau of Reclamation. Colorado Division of Wildlife, Fort Collins, Colorado.

APPENDIX

Table Al. Estimated effect of the Aspinall Unit on mean bi-monthly water temperature in the Gunnison River at River Miles 2 and 20. SNTEMP calculated downstream temperatures using water temperature at the Gunnison Tunnel. Water temperature at the tunnel before construction of Aspinall was estimated by adding 6 °C to March, April, May, and September temperatures and by adding 11 °C to June, July and August temperatures.

	River Mile 2			River Mile 20		
	With Aspinall (°C)	Without Aspinall (°C)	Difference (°C)	With Aspinall (°C)	Without Aspinall (°C)	Difference (°C)
Mar 1-15	6.99	6.95	+ 0.04	6.72	6.68	+ 0.04
Mar 16-31	8.23	8.11	+ 0.12	7.96	7.81	+ 0.15
Apr 1-15	9.27	9.36	- 0.09	8.89	8.98	- 0.09
Apr 16-30	11.59	11.80	- 0.21	11.19	11.42	- 0.23
May 1-15	11.70	12.40	- 0.70	11.28	12.05	- 0.77
May 16-31	12.16	13.04	- 0.88	11.66	12.60	- 0.88
Jun 1-15	14.34	15.59	- 1.25	13.64	15.00	- 1.36
Jun 16-30	17.35	19.28	- 1.93	16.20	18.33	- 2.13
Jul 1-15	19.94	21.64	- 1.70	18.68	20.67	- 1.99
Jul 16-31	22.44	23.41	- 0.97	21.29	22.54	- 1.25
Aug 1-15	22.98	23.60	- 0.62	22.04	22.90	- 0.86
Aug 16-31	21.23	21.69	- 0.46	20.45	21.12	- 0.67
Sep 1-15	19.24	19.64	- 0.40	18.57	19.14	- 0.57
Sep 16-31	16.21	16.82	- 0.61	15.76	16.55	- 0.79

Table A2. Estimated effect of the Aspinall Unit on mean, **bi-monthly** water temperature in the Colorado River at river miles 49 and 136. SNTEMP calculated downstream temperatures using water temperature of the Gunnison River at the Gunnison Tunnel. Water temperature at the tunnel before construction of Aspinall was estimated by adding 6 °C to March, April, May, and September temperatures and by adding 11 °C to June, July, and August temperatures.

	River Mile 49			River Mile 136		
	With Aspinall (°C)	Without Aspinall (°C)	Difference (°C)	With Aspinall (°C)	Without Aspinall (°C)	Difference (°C)
Mar 1-15	8.46	8.46	0	8.53	8.51	+ 0.02
Mar 16-31	9.65	9.62	+ 0.03	9.48	9.43	+ 0.05
Apr 1-15	11.13	11.16	- 0.03	10.60	10.65	- 0.05
Apr 16-30	12.82	12.87	- 0.05	12.47	12.56	- 0.09
May 1-15	13.21	13.37	- 0.16	12.40	12.69	- 0.29
May 16-31	14.75	14.96	- 0.21	12.97	13.27	- 0.70
Jun 1-15	17.15	17.43	- 0.28	14.65	15.03	- 0.38
Jun 16-30	20.85	21.24	- 0.39	17.12	17.65	- 0.53
Jul 1-15	22.97	23.27	- 0.30	19.09	19.52	- 0.43
Jul 16-31	24.41	24.53	- 0.12	20.89	21.12	- 0.23
Aug 1-15	23.96	24.02	- 0.06	20.95	21.09	- 0.14
Aug 16-31	22.53	22.56	- 0.03	19.69	19.79	- 0.10
Sep 1-15	20.71	20.74	- 0.03	18.25	18.35	- 0.10
Sep 16-31	17.51	17.59	- 0.08	15.65	15.85	- 0.20

Table A3. Annual streamflows and estimated annual suspended-sediment loads in the Gunnison River near Grand Junction, 1950-1984. (Data excerpted from Elliott and DeFeyter 1986)

Before Blue Mesa Dam				After Blue Mesa Dam			
Year	Total Discharge (AF)	Total Sediment Load (Tons)	Average Sediment Load (T/AF)	Year	Total Discharge (AF)	Total Sediment Load (Tons)	Average Sediment Load (T/AF)
1950	1,387,000	1,020,000	0.735	1966	1,046,000	550,000	0.526
1951	1,127,000	777,000	0.689	1967	886,500	407,000	0.459
1952	2,625,000	4,270,000	1.627	1968	1,444,000	848,000	0.587
1953	1,331,000	1,100,000	0.826	1969	1,875,000	1,250,000	0.667
1954	663,500	278,000	0.419	1970	2,253,000	1,690,000	0.750
1955	1,032,000	615,000	0.596	1971	2,224,000	1,230,000	0.553
1956	1,113,000	817,000	0.734	1972	1,199,000	533,000	0.445
1957	3,209,000	6,380,000	1.988	1973	2,083,000	1,690,000	0.811
1958	2,383,000	3,590,000	1.507	1974	1,699,000	912,000	0.537
1959	950,900	522,000	0.549	1975	1,816,000	1,340,000	0.738
1960	1,390,000	1,050,000	0.755	1976	1,314,000	640,000	0.487
1961	1,015,000	622,000	0.613	1977	772,800	322,000	0.417
1962	2,194,000	2,580,000	1.176	1978	1,317,000	878,000	0.667
1963	913,800	441,000	0.483	1979	2,343,000	2,020,000	0.862
1964	1,347,000	1,190,000	0.883	1980	2,249,000	2,010,000	0.894
1965	2,611,000	3,290,000	1.260	1981	1,061,000	459,000	0.433
				1982	1,704,000	1,020,000	0.599
				1983	3,147,000	3,840,000	1.220
				1984	3,766,000	5,320,000	1.413
Mean			0.928	Mean			0.688
Standard Error			0.110	Standard Error			0.060
Minimum			0.419	Minimum			0.417
Maximum			1.988	Maximum			1.413

Table A4. Peak streamflow (CFS, highest annual mean-daily flow) for the Colorado River at Cisco and the Gunnison River near Grand Junction.

	Colorado River		Gunnison River			Colorado River		Gunnison River	
Year	Date	Flow	Date	Flow	Year	Date	Flow	Date	Flow
1914	6/03	65,600			1954	5/23	12,200	5/23	3,220
1915	6/13	33,600			1955	6/10	17,200	5/09	7,790
1916	5/11	46,900			1956	6/04	30,000	6/04	8,330
1917	6/19	73,200	6/18	24,800	1957	6/10	63,400	6/07	27,400
1918			6/14	16,900	1958	5/30	48,800	5/24	19,800
1919			5/22	11,200	1959	6/11	21,200	6/16	6,480
1920			5/23	35,200	1960	6/06	25,200	5/14	8,990
1921			6/15	29,800	1961	5/31	20,500	5/29	7,390
1922			5/07	22,200	1962	5/14	43,800	5/13	16,500
1923	5/29	47,100	5/28	18,100	1963	5/21	12,100	5/27	13,000
1924	6/16	49,900	6/07	15,000	1964	5/28	28,600	5/10	4,730
1925	6/01	27,700	4/18	8,660	1965	6/20	37,700	5/23	15,300
1926	5/27	47,500	6/05	13,900	1966	5/11	17,200	5/08	5,360
1927	5/20	48,400	5/19	17,700	1967	5/27	20,500	5/27	4,520
1928	6/01	62,200	5/03	21,400	1968	6/07	30,600	6/04	7,450
1929	5/27	58,600	5/	23,100	1969	4/25	22,200	4/25	9,460
1930	6/01	40,200	5/	12,400	1970	5/24	35,000	6/28	11,100
1931	6/09	17,400	5/	3,760	1971	6/19	22,800	4/15	6,260
1932	5/24	49,600	5/	18,100	1972	6/10	19,000	6/09	3,460
1933	6/03	49,200	6/	17,800	1973	6/16	41,600	5/21	11,900
1934	5/13	16,800	5/12	4,190	1974	5/12	24,700	5/11	7,260
1935	6/16	53,200	6/16	15,800	1975	6/09	29,200	5/21	8,830
1936	5/07	38,300	5/07	14,700	1976	6/07	15,600	5/18	5,120
1937	5/17	39,200	5/17	15,100	1977	6/10	4,970	5/11	1,070
1938	6/06	52,800	5/30	17,300	1978	6/17	30,800	5/17	7,510
1939	5/24	25,000	5/06	7,830	1979	5/30	44,600	5/28	13,200
1940	5/14	25,000	5/13	8,560	1980	5/25	38,400	5/24	13,100
1941	5/15	63,400	5/14	26,200	1981	6/09	11,800	5/04	3,710
1942	5/28	50,000	5/27	20,600	1982	5/06	22,200	5/05	7,960
1943	6/04	32,700	5/05	12,900	1983	6/27	60,500	6/27	20,200
1944	5/17	51,900	5/17	25,600	1984	5/27	69,500	6/08	23,200
1945	5/13	32,400	5/12	14,800	1985	5/06	43,200	5/05	15,100
1946	6/19	26,600	6/08	948	1986	6/08	34,100	5/05	9,830
1947	6/22	38,100	6/22	13,500	1987	5/19	30,500	5/02	9,120
1948	5/23	50,800	5/22	21,000	1988	5/20	14,300	5/19	3,510
1949	6/21	53,200	6/20	18,500	1989	5/25	9,670	4/22	3,620
1950	6/04	23,300	4/24	7,920					
1951	5/30	29,100	5/29	9,790					
1952	6/10	56,300	5/06	22,300					
1953	6/15	38,000	6/14	13,200					

Table A5. Mean-monthly streamflow for the Gunnison River near Grand Junction for three time periods: early development (1917-1938), middle development (1939-1965) and post Aspinall (1966-1988).

	Mean-monthly streamflow (CFS)						Percent Change		
	Early Development		Middle Development		Post Aspinall Development		Early to Middle	Middle to Post	Early to Post
Month	Mean	SEM	Mean	SEM	Mean	SEM			
JAN	878.8	32.1	865.4	21.7	2,195.8	156.3	− 1.5	+153.7	+149.9
FEB	966.5	38.9	907.3	28.8	2,109.0	191.0	− 6.1	+132.4	+118.2
MAR	1,173.2	60.4	1,010.8	43.8	2,223.6	215.4	- 13.8	+120.0	+ 89.5
APR	3,289.8	333.4	3,071.6	380.8	3,027.8	373.1	− 6.6	− 1.4	− 8.0
MAY	9,666.0	845.8	7,418.7	729.2	5,554.6	654.3	- 23.2	- 25.1	- 42.5
JUN	9,251.3	949.3	7,236.5	774.4	4,909.8	725.4	- 21.8	- 32.2	− 46.9
JUL	2,708.9	328.6	2,382.2	469.8	2,319.6	386.5	- 12.1	− 2.6	- 14.4
AUG	1,307.1	189.9	1,211.8	145.7	1,490.1	157.9	− 7.3	+ 23.0	+ 14.0
SEP	1,180.0	222.1	1,033.7	91.8	1,772.0	145.4	- 12.4	+ 71.4	+ 50.2
OCT	1,237.6	106.2	1,181.2	104.3	1,912.1	159.1	− 4.6	+ 61.9	+ 54.5
NOV	1,235.3	57.5	1,182.6	52.8	2,012.9	136.9	− 4.3	+ 70.2	+ 62.9
DEC	1,010.4	27.8	963.3	33.1	2,178.6	137.8	− 4.7	+126.2	+115.6

Table A6. Mean-monthly streamflow for the Colorado River at the Cisco U.S.G.S. stream gage for three time periods: early development (1914-1938), middle development (1939-1965) and post Aspinall (1966-1989).

	Mean-monthly streamflow (CFS)						Percent Change		
	Early Development		Middle Development		Post Aspinall Development		Early to Middle	Middle to Post	Early to Post
Month	Mean	SEM	Mean	SEM	Mean	SEM			
JAN	2,408.7	90.6	2,671.8	63.4	4,073.5	223.0	+ 10.9	+ 52.5	+ 69.1
FEB	2,733.7	97.2	2,874.1	111.2	4,125.1	245.5	+ 5.1	+ 43.5	+ 50.9
MAR	3,375.1	229.6	3,205.1	121.4	4,764.3	346.5	− 5.0	+ 48.6	+ 41.2
APR	9,631.6	805.4	8,317.4	938.1	8,012.2	907.5	- 13.6	− 3.7	- 16.8
MAY	24,442.5	1,915.7	19,392.9	1,694.0	16,915.6	1,912.4	- 20.7	- 12.8	- 30.8
JUN	29,821.7	2,611.9	21,639.5	1,878.1	18,861.4	2,227.7	−27.4	- 12.8	- 36.8
JUL	11,025.0	1,182.6	8,124.7	1,234.9	8,824.1	1,297.5	−26.3	+ 8.6	- 20.0
AUG	5,057.6	643.2	3,738.2	414.9	4,278.3	501.8	-26.1	+ 14.4	- 15.4
SEP	3,980.7	554.0	2,949.5	224.2	4,036.4	304.6	- 25.9	+ 36.9	+ 1.4
OCT	3,869.8	319.5	3,553.5	309.4	4,487.8	330.5	− 8.2	+ 26.3	+ 16.0
NOV	3,280.7	141.1	3,462.2	133.1	4,594.1	267.5	+ 5.5	+ 32.7	+ 40.0
DEC	2,622.7	88.8	2,918.5	88.9	4,285.8	226.0	+ 11.3	+ 46.8	+ 63.4

Table A7. Measured and estimated virgin streamflow for the Gunnison River near Grand Junction, Colorado, 1952-1983.

Years/ Month	Mean-monthly streamflow (CFS)				Percent Change
	Measured Flow		Estimated Virgin Flow		
	Mean	Std. Error	Mean	Std. Error	
1952-1965					
JAN	843.7	29.6	824.0	27.5	+ 2.4
FEB	893.9	47.8	861.3	41.3	+ 3.8
MAR	971.1	58.2	988.6	52.6	– 1.8
APR	2,798.9	480.8	3,335.4	465.6	- 16.1
MAY	6,536.0	1,013.0	8,555.5	1,022.9	- 23.6
JUN	6,986.1	1,301.9	9,367.5	1,364.6	- 25.4
JUL	2,475.7	849.4	3,729.8	870.7	- 33.6
AUG	1,219.9	236.3	2,035.2	270.2	- 40.1
SEP	1,082.5	159.2	1,385.1	166.3	- 21.8
OCT	1,123.6	111.2	1,287.1	106.7	- 12.7
NOV	1,149.4	66.5	1,156.5	66.7	– 0.6
DEC	946.0	49.7	922.7	54.3	+ 2.5
1966-1983					
JAN	2,011.1	169.0	964.4	40.4	+108.5
FEB	1,864.2	203.2	897.3	47.2	+107.8
MAR	1,901.8	210.1	1,235.4	86.2	+ 53.9
APR	2,441.6	302.8	3,121.8	294.6	- 21.8
MAY	4,793.3	562.5	8,729.9	826.7	- 45.1
JUN	4,439.8	705.6	9,434.6	968.1	- 52.9
JUL	1,991.0	393.7	3,798.4	467.6	- 47.6
AUG	1,351.3	168.0	1,869.4	182.4	- 27.7
SEP	1,611.3	153.1	1,552.8	192.0	+ 3.8
OCT	1,726.1	142.9	1,480.9	131.9	+ 16.6
NOV	1,902.8	132.2	1,212.7	64.2	+ 56.9
DEC	2,153.9	145.6	1,024.4	46.2	+110.3

Table A8. Storage capacity of reservoirs mentioned in the text.

Reservoir	Year Completed	Storage Capacity Total (AF)	Active (AF)
Blue Mesa	1966	940,800	748,500
Crystal	1976	26,000	13,000
Crawford	1962	14,395	14,064
Flaming Gorge	1964	3,788,900	3,515,700
Fruitgrowers	1939	4,540	4,460
Green Mountain	1942	154,600	146,900
Grandby	1949	539,800	463,300
McPhee	1984	381,100	229,000
Morrow Point	1968	117,190	42,120
Navajo	1963	1,708,600	1,036,100
Paonia	1962	20,950	18,150
Ridgeway	1987	80,000	55,000
Rifle Gap	1967	13,602	12,168
Ruedi	1968	357,000	327,000
Shadow Mountain	1946	18,400	1,800
Taylor Park	1937	106,200	
Vega	1959	33,800	32,980
Willow Creek	1953	10,600	9,100

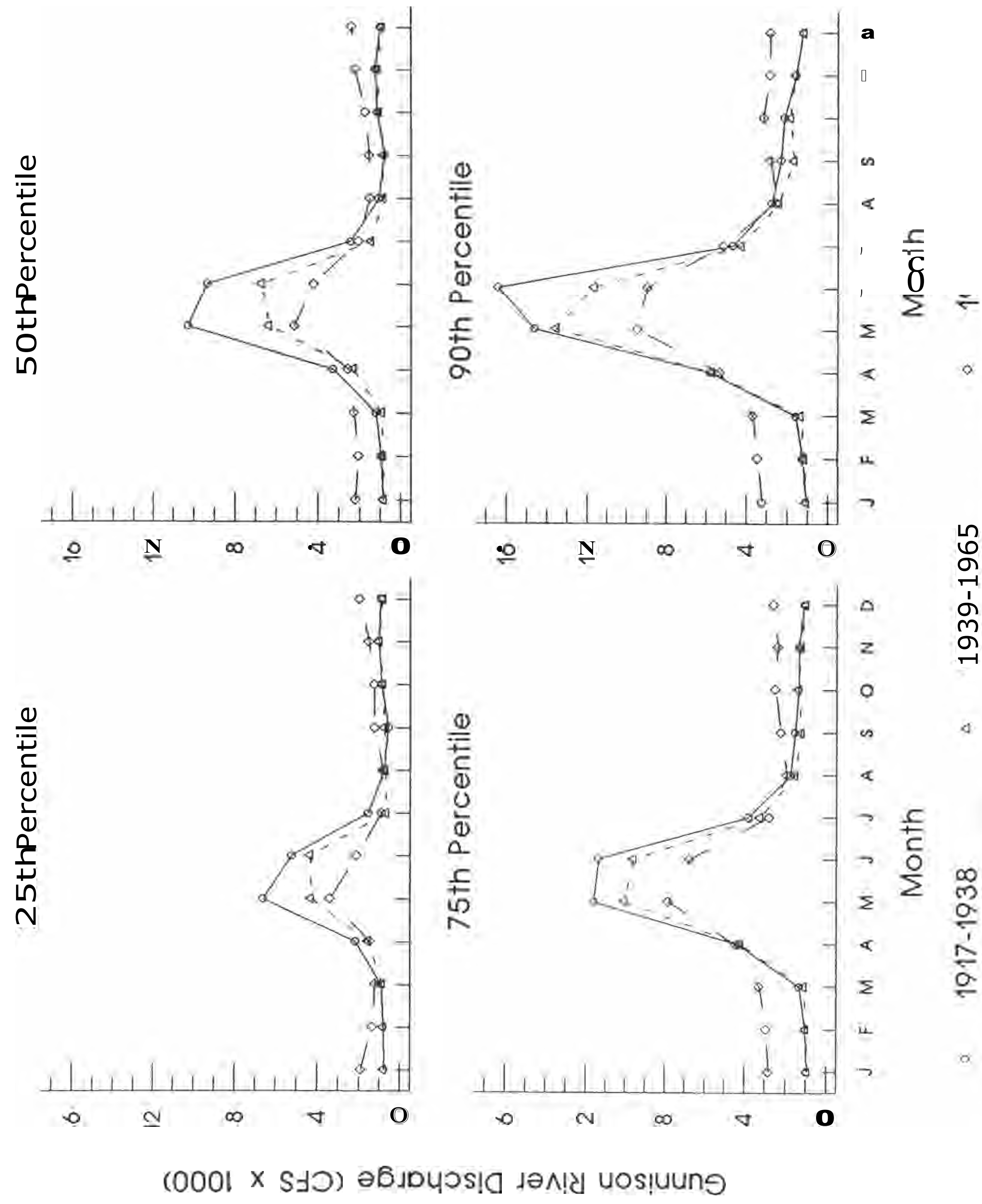

Figure Al. Change in mean-monthly discharge in the Gunnison River near Grand Junction during three time periods: early development (1914-1938), middle development (1939-1965), and post-Aspinall development (1966-1988).

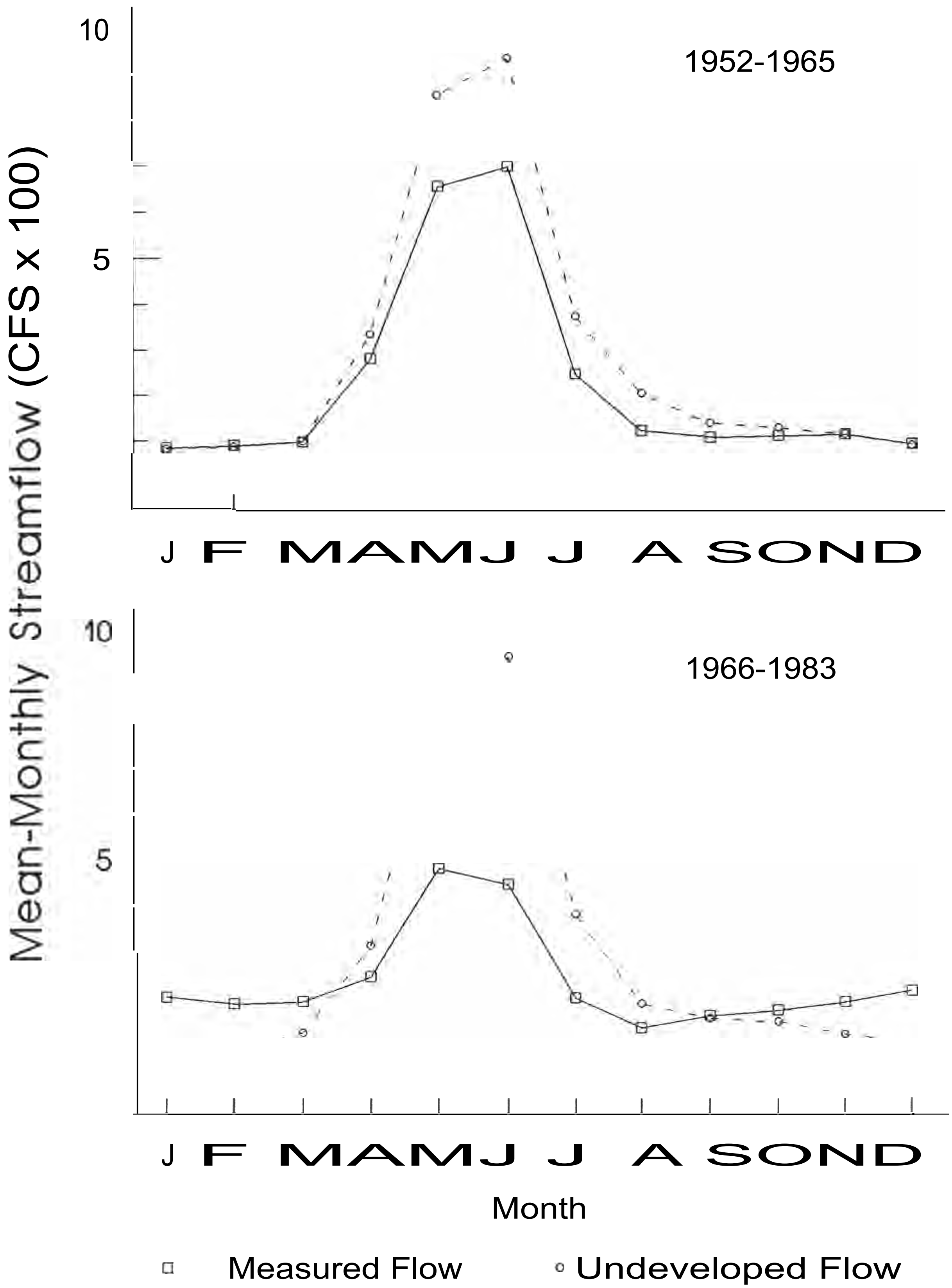

Figure A2. Mean—monthly streamflow of the Gunnison River near Grand Junction, Colorado before (upper, 1952-1965) and after Blue Mesa was completed (lower, 1966-1983). Measured flow was recorded by the U.S.G.S. stream gage at Whitewater. Undeveloped flow (streamflow that would have occurred without any development in the Gunnison River Basin) was estimated using a computer model (HDR Engineering, Inc. 1989).

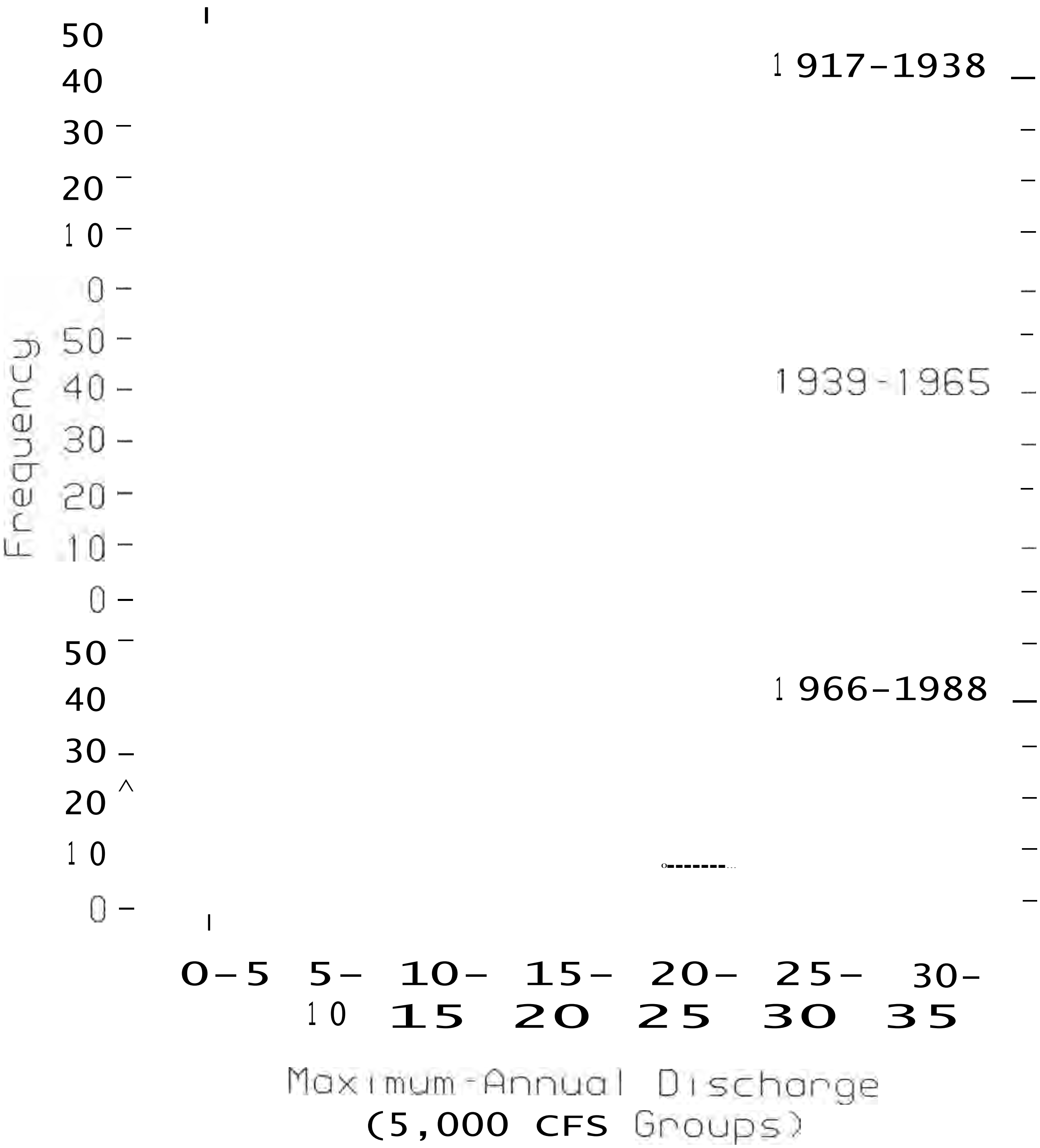

Figure A3. Frequency distribution of maximum-annual discharge (highest mean-daily streamflow for the year) for three periods (early development [1917-1938], middle development [1939-1965], and post-Aspinall development [1966-1988] for the Gunnison River near Grand Junction, Colorado. Streamflows were recorded at the U.S.G.S. stream gage at Whitewater, Colorado

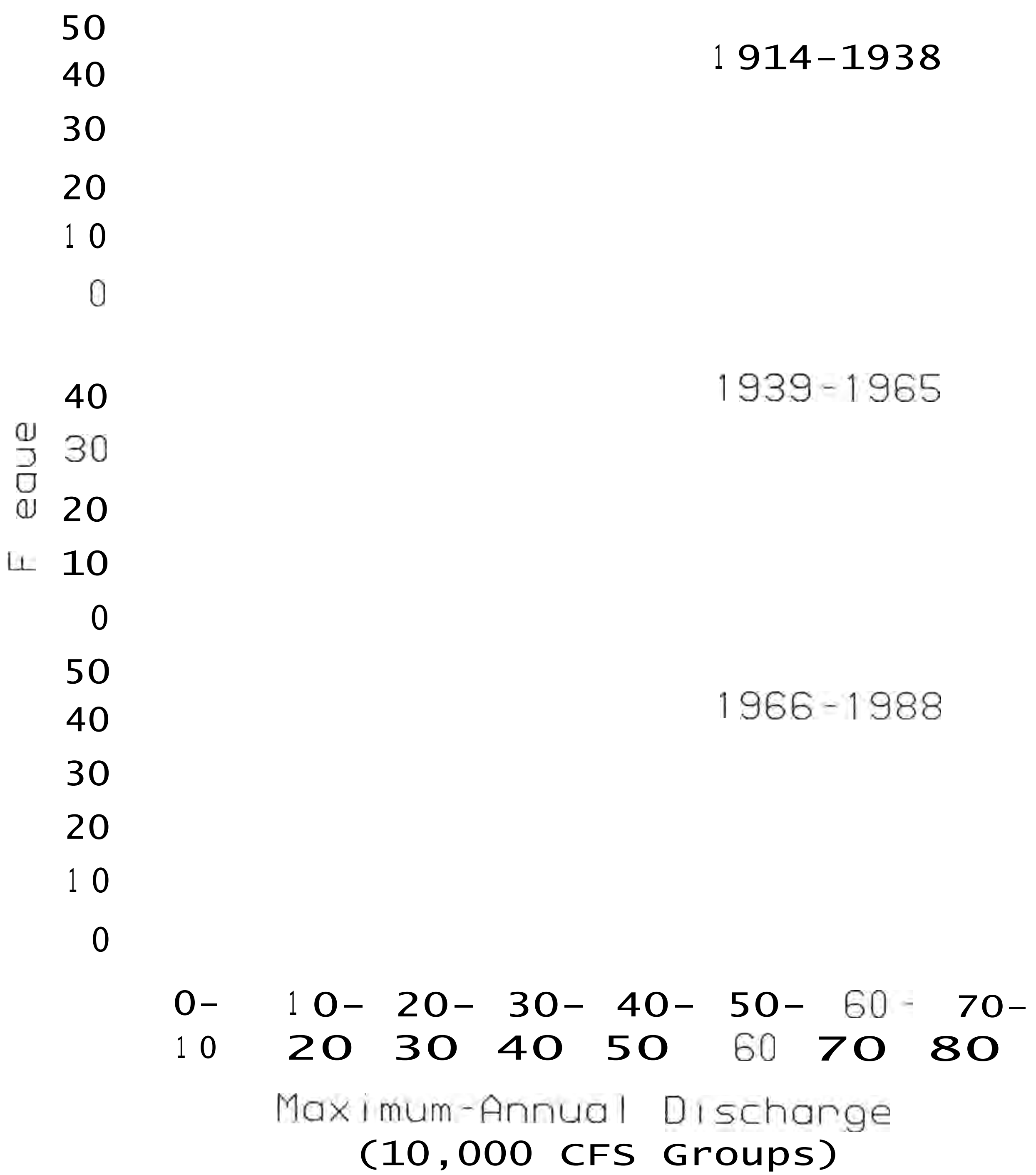

Figure A4. Frequency distribution of maximum-annual discharge (highest mean-daily streamflow for the year) for three periods (early development [1914-1938], middle development [1939-1965], and post-Aspinall development [1966-1988] for the Colorado River at the Cisco, Utah stream gage.

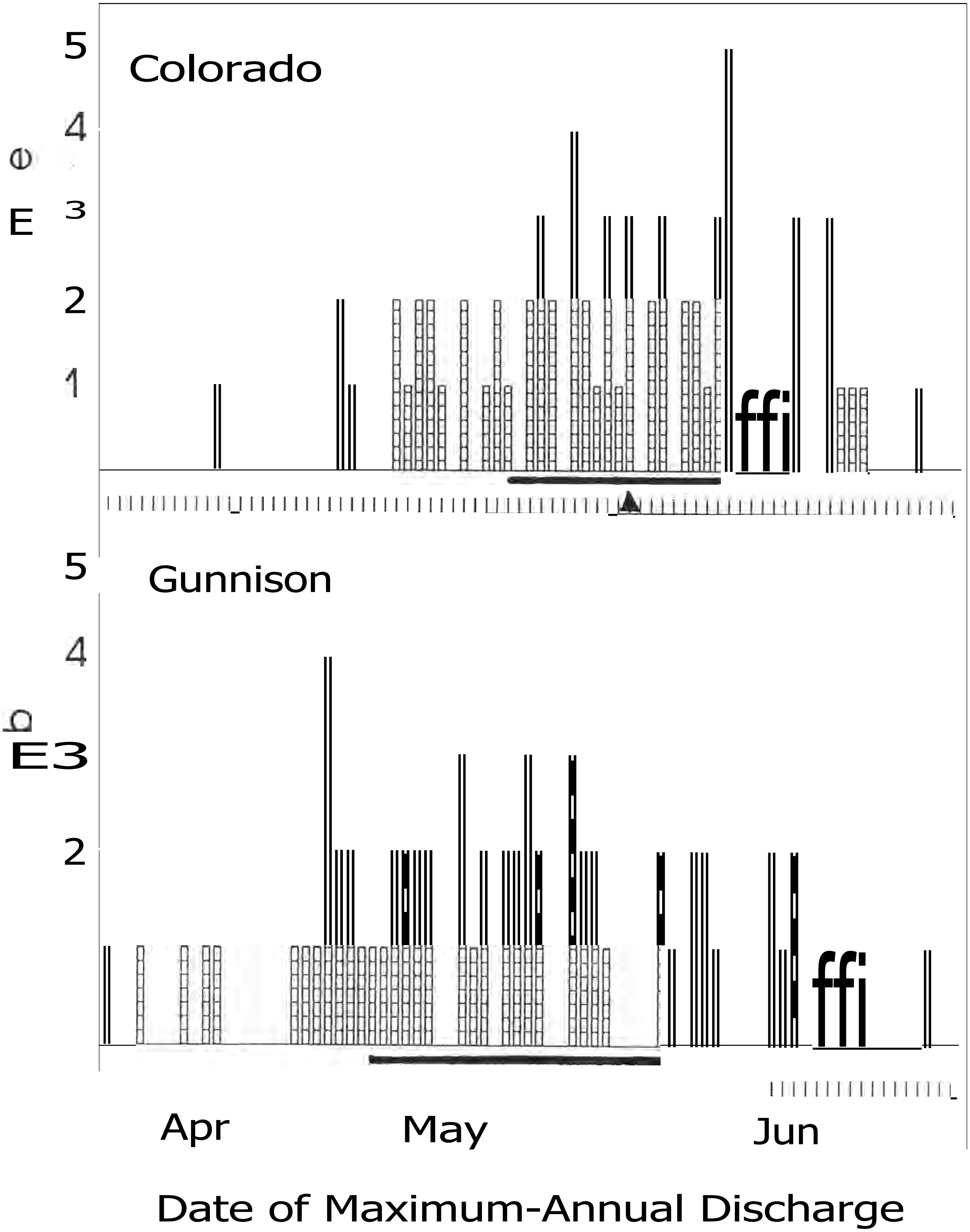

Figure A5. Frequency distribution of the date of maximum-annual discharge for the Colorado River (upper; Cisco gage) and the Gunnison River (lower; Whitewater gage). The black bar equals the middle 50% of the distribution, the triangle equals the mean.